MINER

A study of the loss of head in pipes

Civil Engineering

B. S.

1910

UNIV. OF
ILLINOIS
LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1910
Book M66
Volume

Mr10-20M

Digitized by the Internet Archive
in 2016

https://archive.org/details/studyoflossofhea00mine

A STUDY OF THE LOSS OF HEAD IN PIPES

151144

BY

LESLIE EARL MINER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1910

1918
M66

M66

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING.

June 1, 1910

This is to certify that the thesis prepared in the Department of Municipal and Sanitary Engineering by LESLIE EARL MINER entitled A Study of the Loss of Head in Pipes is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

A N Talbot

Melvin L. Enger

Instructors in Charge.

Approved:

A N Talbot

Professor of Municipal and Sanitary Engineering.

Approved:

Ira O. Baker.

Professor of Civil Engineering.

168949

THE RARE BOOK & MANUSCRIPT LIBRARY
UIUC

CONTENTS.

		PAGE.
I.	INTRODUCTION,	2.
II.	HISTORICAL SKETCH,	3.
III.	ACCEPTED CAUSES OF LOSS OF HEAD AND OBSERVATIONS WHICH MUST BE MADE IN DETERMINING LOSS OF HEAD IN PIPES,	7.
IV.	EXPERIMENTAL DATA,	9.
V.	COMMENTS,	41.
VI.	BIBLIOGRAPHY,	44.

INTRODUCTION.

The object of this thesis is to make a careful study of the principal experiments on pipes and from these to deduce conclusions as to the probable relation of the loss of head in pipes to velocity of flow, diameter of pipes, condition of interior of pipes, etc. The most authentic experiments from the time of Darcy to the present day will be considered. Weight will be given according to the care and method of carrying on the experiments and the making of computations. Tables will be made containing the results of each experiment and two curves will be plotted for each. In one the loss of head will be plotted as ordinates and the velocities will be plotted as abscissae. These will be on logarithmic paper. In the other curve, values of the coefficient c in the well-known Chezy formula , $v = c\ (rs)^{1/2}$, will be plotted as ordinates and corresponding values of v as abscissae. Conclusions will be drawn from these curves.

A third series of curves will plotted as follows. The experiments will be divided into seven groups. These are New Cast Iron, New Wrought Iron, Riveted Sheet Iron, Brass, Galvanized Iron and Water Mains. A curve will be plotted for each group with the value of m in $H = mv^n$ as ordinates and witn the diameters of the pipes as abscissae. An equation will be derived for each curve which will represent the law of the loss of head in friction.

II. HISTORICAL SKETCH.

Since the beginnings of hydraulic science, its followers have been deeply interested in atudying the laws of flowing water. More than 250 years ago Galileo remarked that more was known concerning the motions of the planets and stars than those of the rivers and seas. When, in 1750, the Academy of Science of Berlin offered a prize for the solution of the problem: to state the relation between the mean velocity of a river or canal and its slope and cross-section, the celebrated D'Alembert declared that he, for one, did not think that he had the requisite powers of analysis nor the endurance or courage to undertake the solution of such a problem in the term of a few years. Even the great Euler only made an attempt to solve a modified problem of this kind. Likewise, experimenters who have evolved formulae, have done so by giving some attributes to flowing water and then using the results of their experiments, basing them upon these attributes.

Up to the present day hydraulicians have endeavored to evolve some formula that will satisfactorily explain the flow of water in pipes. They have hoped against hope that one could be found which would be an expression of this natural law. There have been many theories advanced to explain the flow of water in pipes. One of the first was that the different particles of water did not flow past the same point with the same velocity. Weisbach in his "Experimental

[illegible]

[illegible]

[illegible]

Hydraulics" states it about as follows: " Water does not flow past all points of one and the same cross-section of a pipe with one and the same velocity, but, on the contrary, the particles which flow nearest the surface of the pipe have a less, and those more distant from this surface have a greater velocity. This variation in the velocity of efflux past one and the same plane of cross-section has its cause in the cohesion of the water and in its adhesion to the pipe surface. The body of water contained in the pipe may be likened to the trunk of a tree: just as a tree-trunk is composed of annually accumulated layers, the one within the other, so is the water flowing in a pipe composed of a lot of hollow tubes, which similarly surround and contain each other." This theory was eventually disproved by suddenly injecting some colored liquid into a pipe flowing full and observing the position of the coloring at long distances below this point.

For a long time the right-line theory of motion was assumed to be true. This theory assumes that the loss of head varies directly as the velocity of flow. It was finally recognized that this was true for only very small velocities and that above a certain velocity, called the critical velocity, and varying for different sizes of pipes. Then it was thought that, above this critical velocity, the loss of head varies as the square of the velocity. Many formulae have been based on this latter theory. In nearly all of these formulae there were coefficients which were supposed to be constant for different pipes. It was through the varying of these coefficients that it was concluded that the loss of head does

not vary as the square of the velocity, but as some power of the velocity less than two.

Thus we have a large number of empirical formulae which, at first sight, appear to be based on sound reasoning but are really based on hydraulic assumptions. It is probably because of this fact that in the 160 years of study and experiment since 1750 very little has been definitely accomplished toward ascertaining any law of flowing water, notwithstanding all this work. This statement is made considering the fact that no formula exists which gives satisfaction.

From among all these formulae the one which has best stood the test of time is the Chezy formula, $v = c(rs)^{1/2}$, where v is the velocity, usually in feet per second; c is a coefficient; r is the hydraulic radius and s is the loss of head in feet of water. Perhaps the main reason for this formula surviving others is its simplicity and convenience.

It is perhaps interesting that this formula which is so often used by civil engineers has an unknown origin. It is first found in an embryonic condition in a book by Albert Brahms on "Dikes and Other Hydraulic Constructions" published in 1757. Brahms does not give any formula but says that "the velocities of water are as the square roots of the slopes" and that "the values of friction at equal slopes of water surface are to each other, in case of open flowing water, as the areas wetted by the water are to the quantities that flow over them." He also gives the depths, velocity, and slopes of two rivers, so that Hagen was enabled to compute (in 1876) Brahms meant $v = 97.6\ (rs)^{1/2}$. In 1769,

Perronet and Chezy were appointed to report on the proposed canal de l'Yvette to bring water into Paris. In 1775, Chezy made a report addressed to Perronet, but which was never printed. This report is said to have contained the original Chezy formula. Thus it was originally evolved to represent the flow of water in channels but hydraulicians have found that it serves satisfactorily for pipes. Because this formula is better known than others it has been used in the following data.

III. ACCEPTED CAUSES OF LOSS OF HEAD

and

OBSERVATIONS WHICH MUST BE MADE IN DETERMINING LOSS OF HEAD IN PIPES.

The resistance to flow of water in pipes has been generally accepted by all hydraulicians to be due to two causes. The first is the friction of the water on the inner surface of the pipe. The second source of loss of energy results from eddies produced in the water by irregularities in the inner surface of the pipe. This latter has been neglected until recently as a cause of loss of head. When water flows through a pipe with a rough surface, a disturbance is caused in the stream of water, which may extend entirely through the mass, and it is the internal work of friction resulting from these eddies that constitutes by far the larger part of the total energy consumed in the flow. The relative importance of these two factors depends much upon the velocity of the flow and upon the diameter of the pipe as well as on roughness. For low velocities and small diameters, resistance is largely due to friction on the inner surface of the pipe and varies closely with the velocity; for larger velocities and pipes the loss varies nearly as the square of the velocity.

Hamilton Smith, in his Hydraulics, gives the following five things as necessary to determine in experimentation with pipes.

(1). The total head H, which is for a submerged discharge, the difference in elevation between the surface of the water in

the feeding reservoir, and the surface in the outlet reservoir. For discharge free into the air, H is the difference in elevation between the surface of the water in the feeding reservoir, and the center of the escaping jet in the plane of the lower end of the pipe.

(2). The total length, l, which should be measured following all the sinuosities of the pipe when it is curved.

(3). The mean diameter, D.

(4). The amount of discharge in a known period of time, or q.

(5). The segregation of h' and h from H, the total loss of head. h is the loss of head due to entrance while h' is the actual loss of head in the pipe due to friction.

In pipes of very small diameters or with exceedingly low velocities for large diameters, the temperature of the water has a very important effect upon the viscosity or adhesion of the water to the wetted surface of the tube. Experimenters differ on the question as to whether to take temperature into account.

All experimenters practically agree with Hamilton Smith that these are the necessary observations.

IV. EXPERIMENTAL DATA.

In this article each series of experiments will be taken up and a short description will be made of the experiments, the size and condition of the pipes and the care taken in making the experiments.

JARNES SIMPSON.

In 1853, Jarnes Simpson made a number of experiments on a 19 inch cast-iron water main. They appear to have been carefully made.

DARCY.

From 1849 to 1851, Henry Darcy made a very elaborate and costly series of experiments upon the flow of water through pipes. These were made on the water pipes of Paris , Darcy being in charge of the water service of Paris during that time. The experiments which are tabulated in this thesis were made on clean, new, cast-iron pipes; old, coated, cast-iron pipes; new wrought iron pipes, and sheet iron pipes, covered with bitumen. All of the pipes were straight, with a slight upward inclination towards the outlet. The diameters varied from 1 inch to 11.2 inches and the lengths were all about 367 feet. During the experiments, the upper or inlet end of each pipe was successively attached to the end of a closed cylinder. A constant head for each experiment was obtained by a feeding pipe connected with this cylinder. The loss of head in the pipe was determined by means of piezometric tubes

attached to the pipes, one at each end, and several along the pipe. The absolute volume of discharge was measured in tanks of considerable capacity so that the period of time of each experiment was amply great. The mean sections and diameters were determined either by measuring the volume of water contained in the experimental pipe or by two direct linear measurements at each of the two ends of each joint. Thus the mean velocity was accurately determined. While Darcy made his experiments with much care, he was careless in tabulating his results, with the result that there are many errors in his published volume.

IBEN.

In 1880, Herr Otto Iben published a large number of experiments on the flow of water in cast-iron pipes made during the years 1874 - 1879 by engineers in charge of the water-works of Hamburg. Herr Iben simply acted as editor in compiling the data given to him. The several elements were determined as follows: Discharge by absolute measurements during an observed period of time; D, by carefully measuring a few joints of the commercial size in use and by end diameters; length by measurement; and the loss of head by means of Bourdon gauges. These gauges were carefully compared for correction by attaching them to a vertical standpipe before and after each series of experiments. The pipes were new and had all been coated with tar, hence probably having smooth interior surfaces.

LAMPE.

In 1869 - 1871, Prof. Dr. C. J. H. Lampe made some very accurate experiments on a long cast-iron conduit near Danzig. The pipe was 16-1/2 inches in diameter and 35,312 feet long. It was laid in 1869 and was coated with a patent varnish. When examined in 1871, the character of the inner surface was found to be unchanged. The mean velocity was ascertained by measuring the discharge in a masonry reservoir situated at the outlet of the pipe. This reservoir was large enough to afford an excellent opportunity for the accurate determination of the velocity. The losses of head were determined by means of quicksilver manometers. Dr. Lampe states that he is satisfied that there is no serious error in this method of the determination of the losses of head.

FREDERICK P. STEARNS.

In 1885, Frederick P. Stearns made some very careful experiments on a cast-iron conduit pipe having a diameter of 48 inches and a length of about 1800 feet. This pipe formed a portion of the Sudburg conduit line for the water supply of the City of Boston and was known as the Rosemary pipe. The pipe had been laid three years before these experiments; it had originally been coated with a preparation of coal-tar and asphaltum, and at the time of these experiments its interior surface appeared to be very nearly in as good order as when the pipe was first laid. The discharge was determined by the flow over a weir, ten miles distant from the pipe, and an

additional allowance was made for the infiltration into the conduit between the measuring weir and the pipe. The coefficients of discharge for this weir had been accurately determined so that for these experiments the velocity can be considered to be given with sufficient exactness. The head lost was determined by two piezometric columns of water placed near the extremities of the pipe. The relative elevations of the zeros on the two piezometric scales were very accurately determined. The pipe was of nearly uniform diameter, so that the given mean area was within a small fraction of the truth.

CLEMENS HERSCHEL.

During the years 1887 to 1897 Clemens Herschel carried on many experiments on riveted, steel conduits. In all, three different sizes were used, 36 inch, 42 inch and 48 inch. There were two different 48 inch conduits and two of the 42 inch conduits. One each of the 48 inch and 42 inch conduits had cylinder-joints, and the others taper joints. The 36 inch conduit had cylinder-joints. The rivet-heads in these conduits were all well formed. Shop-rivets had been driven with a hydraulic riveter; field rivets with a cup, or set. All plate-edges had been bevel-planed. All of these pipes were dipped in asphalt before being laid and had very smooth coats. The discharges were measured in three ways: by means of a Venturi meter, over a weir, and in tanks or reservoirs. Herschel estimates that each of these methods were correct to within one per cent. He also used three methods of measuring the losses of head. The first was by measuring the difference

in elevation between the surface of the feeding reservoir and the surface of the receiving reservoir. Hook-gauges were used in determining this. The second was for free discharge into air and was determining the difference in elevation between the surface of feeding reservoir and the center of the escaping jet. The third method was by using mercury columns. All of these measurements were taken in the field by J. Waldo Smith, the man who is now Chief Engineer of the great Catskill Aqueduct project of New York City. The diameters were determined by careful lineal measurements.

HAMILTON SMITH.

In 1876, Hamilton Smith made a series of experiments at North Brookfield, California. The ones tabulated in this thesis were on sheet iron pipes from 11 inches to 15 inches in diameter. They had been in use about five years. They were made in single riveted joints, each about 20 feet long, put together stove-joint fashion, one end being slightly larger than the other. The pipes had been originally coated by immersion in a boiling bath of asphaltum and coal tar; at the time of these experiments the interior surfaces were quite smooth, and absolutely free from rust. The diameters were obtained by measurement of the pipes. The total loss of head was found by measuring the difference in elevation between the surface of water in the feeding reservoir and the centre of the escaping jet, the discharge being free in air. The discharge was measured in a carefully calibrated reservoir and the velocity determined from this. For each experiment

from 30 to 50 minutes was allowed for the flow to become constant and the discharge was read for periods of from 5 to 13 minutes. In determining the actual loss of head in the pipe the entrance loss was taken to be $v^2,2g0^2$, where v is the velocity in feet per second, g is the acceleration due to gravity, and 0 is the coefficient of velocity at the entrance. Smith's experiments are undoubtedly of great accuracy.

CHARLES G. DARRACH.

In 1878, Charles G. Darrach carried on a series of experiments on two pumping-mains in Philadelphia. These mains were 20 inches and 36 inches in diameter respectively. They had been laid seven years at this time and the interior surfaces were partially incrusted. The diameters were determined by several accurate linear measurements. The discharge was measured in a reservoir. The loss of head was determined by means of water columns.

SCHODER and GEHRING.

During the years 1906 and 1907, Schoder and Gehring carried on some very interesting experiments on spiral riveted pipes. These were eleven pipes in all from 2 inches to 8 inches in diameter. The 8 inch pipe had been in use three years, while the others had been in use part of one year. All of the experimental sections were straight and no readings were taken under at least 100 diameters from the points of

tangency. The losses of head were measured by means of differential water columns. The diameters were obtained by direct lineal measurement and the discharges by means of a reservoir. All of these elements were very accurately determined in the estimation of the experimenters. A description of the pipes follows.

8 inch-	Cast-iron. Asphalted Hub and spigot joints.
6 "	Wrought-iron. Standard spiral-riveted. Asphalted.
6 "	Cast-iron. " " " "
6 "	Double extra heavy galvanized. "
5 "	Wrought-iron. Standard spiral-riveted. "
5 "	Seamless drawn brass." " " "
4 "	Wrought-iron. " " " "
4 "	" " " " " "
3 "	" " " " "
2 "	" " " " " "

MARX, WING and HOSKINS.

Messrs. Marx, Wing and Hoskins in 1899 conducted a series of experiments on a six-foot wood stave pipe line of the Pioneer Electric Power Company of Ogden, Utah.

The interior surface of the pipe was smooth. Mercury gauges of the ordinary open manometer type were used in measuring the loss of head. They were corrected for temperature. The discharge was measured with a Venturi meter with an automatic registering device. The authors considered this as a very accurate method of measuring discharge. The velocity was figured from the discharge.

SAPH and SCHODER.

Saph and Schoder, during 1901 -02 and 1903, carried on a very extensive series of experiments on 15 seamless drawn brass pipes and 5 galvanized iron pipes. These were carried on at Cornell University where the apparatus was of the very best. The brass pipes were from 0.107 inches to 1.498 inches in diameter. The galvanized pipes were from 0.35 to 1.036 inches in diameter. In experimentation, all pipes were laid straight. In order to eliminate possible errors the pipes were turned end for end and each series repeated.

The different elements were determined as follows. All lengths were measured with an accurate steel tape and were checked by independent measurements. The diameters were measured by cutting off rings from the ends of all of the brass and galvanized-iron pipes and four diameters were measured on each ring. The mean of these four diameters was taken as correct. The discharge was determined both by direct measurement and by weight, the latter being corrected for temperature. Time was taken from a record sheet of a chronograph. Losses of head were measured by means of carefully calibrated piezometers.

All of these pipes were new. The ends of all the pipes were faced and threads so cut that a smooth butt joint was obtained. The inner surfaces of the brass pipes were very smooth, but those of the galvanized pipes were comparatively rough. Temperatures were taken into account in each experiment.

Each experiment will be tabulated, as follows. Five quantities will be given. In the first column v will be tabulated in feet per second. In the second column is the loss of head in feet of water per thousand feet of pipe. This is with the exception of the last series by Saph and Schoder where h' will be given as loss of head in feet of water per one hundred feet of pipe. In the third column are values of the coefficient, c, in the Chezy formula, $v = c(rs)^{1/2}$. In the fourth and fifth columns are values of m and n found graphically from the plotting on logarithmic paper of head to velocity. The equation of the resulting line is $H = mV^n$.

JAMES SIMPSON

Table 1.

D = 19"
Water-Main.

V ft./sec.	h' ft./1000ft.	c	m	n
2.058	1.070	100	0.21	2.10
2.524	1.515	103	0.21	2.10
2.803	1.935	101	0.21	2.10

DARCY

Table 2

D = 1"
New W.I

V ft./sec.	h' ft./1000ft.	c	m	n
1.207	10.15	81.1	6.9	1.91
1.713	19.37	83.3	6.9	1.91
2.612	43.48	84.8	6.9	1.91
3.153	63.16	84.9	6.9	1.91
4.052	100.00	86.7	6.9	1.91

Table 3

D = 1.55"
New. W.I

V ft./sec.	h' ft./1000ft.	c	m	n
1.250	6.50	86.3	4.2	1.86
2.585	23.89	92.9	4.2	1.86
3.593	43.48	95.7	4.2	1.86

DARCY

Table 4

D = 7.72"
Sheet Iron

V ft./sec.	h' ft./1000 ft.	c	m	n.
1.529	1.29	106.2	0.564	1.775
2.559	3.30	111.1	0.564	1.775
3.530	5.80	115.6	0.564	1.775
5.436	11.90	124.3	0.564	1.775
7.410	21.00	127.6	0.564	1.775
9.000	29.70	130.2	0.564	1.775
10.103	36.40	130.9	0.564	1.775

Table 5-a.

D = 11.2"
Sheet Iron.

V ft./sec.	h' ft./1000 ft.	c	m	n
2.782	2.55	114.0	0.363	1.84
3.868	4.33	121.6	0.363	1.84
4.902	6.85	122.5	0.363	1.84
6.673	11.90	126.5	0.363	1.84
8.852	20.44	128.1	0.363	1.84
10.522	28.07	129.9	0.363	1.84

DARCY

Table 5-b.

D. = 3.23"
Sheet Iron

V ft./sec	h' ft./1000ft.	C	m	n
1.17	2.03	99.9	1.50	1.84
2.18	6.29	105.7	1.50	1.84
3.12	12.20	108.4	1.50	1.84
4.44	22.85	112.9	1.50	1.84
5.29	31.07	115.3	1.50	1.84
6.15	40.70	117.1	1.50	1.84

Table 6

D = 3.23"
New C.I.

V ft./sec.	h' ft./1000ft	C	m	n
2.595	10.20	99	2.58	1.98
3.889	22.55	100	2.58	1.98
5.151	40.41	100	2.58	1.98
8.048	95.47	100	2.58	1.98

Table 7

D = 5.4"
New C.I

V ft./sec.	h' ft./1000ft.	C	m	n
2.50	4.75	108.0	0.774	1.97
4.19	12.60	111.0	0.774	1.97
6.88	33.18	112.7	0.774	1.97
7.48	39.05	113.0	0.774	1.97
11.94	98.52	113.5	0.774	1.97.

DARCY

Table 8

D = 11.7"
New C.I

V ft./sec.	h' ft./1000 ft.	c	m	n
5.40	11.05	104.5	0.382	2.00
7.83	23.05	104.6	0.382	2.00
9.17	32.05	103.9	0.382	2.00
10.36	41.06	104.1	0.382	2.00

Table 9

D = 7.4"
New C.I

V ft./sec.	h' ft./1000 ft.	c	m	n.
2.50	3.68	104.4	0.564	2.00
4.90	13.40	107.4	0.564	2.00
6.37	22.50	107.7	0.564	2.00
8.26	38.10	107.3	0.564	2.00
14.23	109.80	109.0	0.564	2.00

Table 10-a.

D = 3.15
Old C.I

V ft./sec.	h' ft./1000 ft.	c	m	n.
1.46	7.25	67.3	3.47	1.95
2.22	16.10	68.7	3.47	1.95
3.05	31.00	67.9	3.47	1.95
3.74	45.35	68.9	3.47	1.95

DARCY

Table 10-b

D = 19.7"
New C.I

V ft./sec.	h' ft./1000ft.	c	m	n
2.60	1.2	117.3	0.285	2.00
3.42	2.1	116.4	0.285	2.00
3.70	2.5	115.6	0.285	2.00

Table 11

D = 9.63"
Old C.I.

V ft./sec.	h' ft./1000ft.	c	m	n.
2.32	4.73	75.5	0.89	2.00
5.07	22.90	75.1	0.89	2.00
6.02	32.00	75.3	0.89	2.00
6.80	41.05	75.2	0.89	2.00
12.58	139.81	75.3	0.89	2.00

CLEMENS HERSCHEL

Table 12

48" Conduit

V ft./sec.	h' ft./1000ft.	c	m	n
3.2	1.18	93.5	0.116	2.05
4.0	1.84	94.0	0.116	2.05
5.4	3.50	94.6	0.116	2.05
6.6	—	95.0	0.116	2.05

HERSCHEL

Table 13

36" Conduit

V ft./sec.	h' ft./1000ft.	C	m	n
3.0	1.13	103.4	0.191	1.55
4.3	1.95	112.5	0.191	1.55
5.5	2.78	121.0	0.191	1.55
6.4	3.45	125.8	0.191	1.55

Table 14

42" Taper Joint

V ft./sec.	h' ft./1000ft.	C	m	n
3.23	1.05	113.0	0.0759	2.31
3.61	1.15	113.0	0.0759	2.31
4.26	1.80	112.5	0.0759	2.31

Table 15

48" Taper Joints

V ft./sec.	h' ft./1000ft.	C	m	n
3.90	1.40	104	0.0975	2.00
4.61	1.99	105	0.0975	2.00
4.71	2.04	105	0.0975	2.00

HERSCHEL

Table 16

42" Taper Joints

V ft./sec.	h' ft./1000 ft.	C	m	n
3.63	1.31	109.4	0.0114	1.92
4.59	2.04	110.2	0.0114	1.92
5.00	2.40	111.0	0.0114	1.92

HERR IBEN

Table 17

$D = 12''$
Bonn Waterworks.

V ft./sec	h' ft./1000 ft.	C	m	n
1.568	1.208	90.1	0.553	1.60
2.116	1.852	98.1	0.553	1.60
2.595	2.690	99.9	0.553	1.60
3.125	3.445	106.5	0.553	1.60

LAMPE

Table 18

$D = 16\frac{1}{2}''$
Clean C. I. — Danzig Conduit Pipe

V ft./sec	h' ft./1000 ft.	c	m	n
2.48	1.375	114.1	0.437	1.75
2.71	1.628	114.6	0.437	1.75
3.09	1.950	119.4	0.437	1.75

F. P. STEARNS

Table 19

$D = 48''$
Clean C. I — Asphalt Coated

V ft./sec.	h' ft./1000 ft.	c	m	n
4.97	1.22	142.1	0.0592	1.89
6.20	1.85	144.1	0.0592	1.89

HAMILTON SMITH

Table 20

$D = 11''$
Riveted Sheet Iron.

V ft./sec.	h' ft./1000 ft.	c	m	n
4.71	8.50	107.1	0.527	1.79
6.93	16.95	111.5	0.527	1.79
8.66	25.59	113.4	0.527	1.79
10.02	33.09	115.5	0.527	1.79

HAMILTON SMITH Table 21

D=12.7
Riveted Sheet Iron

V ft./sec	h' ft./1000ft.	C	m	n
4.60	6.68	109.4	0.361	1.90
6.96	14.28	113.4	0.361	1.90
8.65	22.19	113.0	0.361	1.90
10.70	33.18	114.4	0.361	1.90

Table 22

D = 14.8"
Riveted Sheet Iron

V ft./sec.	h' ft./1000ft.	C	m	n
4.38	5.02	111.6	0.308	1.86
6.84	10.97	117.8	0.308	1.86
8.46	16.46	119.0	0.308	1.86
10.59	24.70	121.6	0.308	1.86
12.09	32.31	122.0	0.308	1.86

CHARLES G. DARRACH

Table 23

D=20"
Pumping Mains L = 4320'

V ft./sec.	h' ft./1000ft.	C	m	n
2.71	3.98	68	1.08	1.31
3.01	4.54	69	1.08	1.31
3.31	5.22	71	1.08	1.31

DARRACH Table 24

$D = 36''$
Pumping Mains $L = 3700'$

V ft./sec	h' ft./1000ft.	c	m	n
1.74	1.09	61	0.72	1.45
2.05	1.40	63	0.72	1.45
2.37	1.72	66	0.72	1.45

SCHODER and GEHRING

Table 25

8" C.I.
Asphalted. Hub and spigot joints.

V ft./sec.	h' ft./1000ft.	C.	m.	n.
1	0.59	101	0.59	1.91
3	4.90	106	0.59	1.91
5	12.50	108	0.59	1.91
10	47.90	112	0.59	1.91

Table 26

6" W. I.

V ft./sec.	h' ft./1000 ft.	C.	m.	n.
1	0.60	115	0.60	1.94
3	5.10	119	0.60	1.94
5	13.60	120	0.60	1.94
10	52.10	123	0.60	1.94

Table 27

6" W. I.
Asphalted. Standard spiral riveted.

V ft./sec.	h' ft./1000ft.	C.	m.	n.
1	0.80	100	0.80	1.85
3	6.12	109	0.80	1.85
5	15.30	113	0.80	1.85
10	56.80	119	0.80	1.85

SCHODER & GEHRING Table 28

6" W. I.
Double extra heavy galvanized

V ft./sec.	h' ft./1000ft.	C	m.	n.
1	0.97	92	0.97	1.92
3	7.98	96	0.97	1.92
5	21.12	98	0.97	1.92
10	80.98	101	0.97	1.92

Table 29

5" W. I.

V. ft./sec.	h' ft./1000ft.	C.	m	n
1	0.99	98	0.99	1.91
3	8.21	103	0.99	1.91
5	21.52	105	0.99	1.91
10	81.24	109	0.99	1.91

Table 30

5" Brass
Seamless drawn.

V ft./sec	h' ft./1000ft.	C.	m.	n
1	0.92	102	0.92	1.79
3	6.73	114	0.92	1.79
5	16.35	121	0.92	1.79
10	57.04	130	0.92	1.79

SCHODER & GEHRING

Table 31

4" W. I

V ft./sec.	h' ft./100ft.	C	m	n
1	1.18	100	1.18	1.95
3	9.92	103	1.18	1.95
5	27.45	104	1.18	1.95
10	99.82	106	1.18	1.95

Table 32

4" W. I
With laps.

V ft./sec	h' ft./1000ft	C	m	n
1	1.34	94	1.34	1.85
3	9.91	102	1.34	1.85
5	26.15	106	1.34	1.85
10	93.40	111	1.34	1.85

Table 33

4" W. I
Against laps.

V ft./sec	h' ft./1000ft.	C	m	n.
1	1.45	90	1.45	1.84
3	10.91	98	1.45	1.84
5	27.94	102	1.45	1.84
10	99.98	108	1.45	1.84

SCHODER & GEHRING

Table 34

3" W. I.

V ft./sec	h' ft./1000ft.	C	m	n
1	1.62	97	1.62	1.91
3	13.205	102	1.62	1.91
5	34.95	105	1.62	1.91
10	131.40	108	1.62	1.91

Table 35

2" W. I.

V ft./sec	h' ft./1000ft.	C	m	n
1	3.15	86	3.15	1.98
3	27.65	87	3.15	1.98
5	76.25	87	3.15	1.98
10	182.50	88	3.15	1.98

MARX WING and HOSKINS

Table 36

72" Wood Stave Pipe.

V ft./sec.	h' ft./100ft.	C	m	n
4.339	1.177	103.1	0.0089	1.78
4.779	1.379	104.9	0.0089	1.78
5.320	1.696	105.3	0.0089	1.78

SAPH and SCHODER

BRASS PIPE

Table 37

D = 2.088″

V ft./sec.	h′ ft./100ft.	C	m	n.
2.713	1.545	108	0.252	1.749
2.886	1.604	113	0.252	1.749
3.737	2.813	107	0.252	1.749
4.550	3.963	112	0.252	1.749
4.854	4.440	111	0.252	1.749
5.701	5.341	118	0.252	1.749
5.766	5.989	113	0.252	1.749

Table 38

D = 1.500

V ft./sec.	h′ ft./100ft.	C	m	n
2.029	1.300	97	0.372	1.754
2.576	1.960	104	0.372	1.754
3.095	2.690	106	0.372	1.754
7.060	11.580	117	0.372	1.754
8.280	15.830	118	0.372	1.754
8.994	17.700	121	0.372	1.754
9.037	18.340	120	0.372	1.754

SAPH & SCHODER
BRASS PIPE

Table 39

$D = 1.245''$

V ft./sec.	h' ft./100ft.	c	m	n
1.813	1.40	95	0.485	1.744
2.279	2.88	84	0.485	1.744
3.384	4.06	103	0.485	1.744
4.097	5.61	107	0.485	1.744
5.052	7.92	111	0.485	1.744
5.959	11.34	110	0.485	1.744
7.135	15.54	111	0.485	1.744

Table 40

$D = 1.069''$

V ft./sec	h' ft./100ft.	c	m	n.
1.438	1.119	91	0.584	1.747
2.415	2.707	95	0.584	1.747
3.087	4.146	96	0.584	1.747
4.864	9.140	108	0.584	1.747
5.285	11.010	107	0.584	1.747
7.044	18.200	111	0.584	1.747
8.609	25.220	115	0.584	1.747

SAPH & SCHODER
BRASS PIPE

Table 41

D = 0.832"

V ft./sec.	h' ft./100ft.	c	m	n.
1.252	1.28	84	0.770	1.737
2.322	3.66	92	0.770	1.737
4.133	9.54	99	0.770	1.737
5.194	14.38	104	0.770	1.737
6.368	20.47	107	0.770	1.737
7.712	28.93	108	0.770	1.737
9.316	40.15	112	0.770	1.737
11.477	59.97	111	0.770	1.737

Table 42

D = 0.630"

V ft./sec.	h' ft./100ft	c	m	n.
1.075	1.206	100	1.165	1.753
1.881	3.282	91	1.165	1.753
3.521	10.770	93	1.165	1.753
5.208	21.130	102	1.165	1.753
6.525	30.950	103	1.165	1.753
7.635	40.770	104	1.165	1.753
8.836	52.370	106	1.165	1.753
10.940	78.450	108	1.165	1.753

SAPH & SCHODER
BRASS PIPE

Table 43

D = 0.498"

V ft./sec.	h' ft./100ft	C	m	n.
1.850	4.54	85	1.53	1.732
2.216	6.55	86	1.53	1.732
3.584	15.07	91	1.53	1.732
4.553	22.78	94	1.53	1.732
5.389	30.66	97	1.53	1.732
6.691	44.20	99	1.53	1.732
7.370	58.60	95	1.53	1.732
8.791	81.30	96	1.53	1.732

Table 44.

D = 0.376"

V ft./sec.	h' ft./100ft.	C.	m.	n.
1.343	3.53	81	2.040	1.763
3.119	15.06	91	2.040	1.763
4.356	27.24	94	2.040	1.763
5.371	39.29	97	2.040	1.763
6.777	59.15	99	2.040	1.763
7.751	86.20	95	2.040	1.763

SAPH & SCHODER
BRASS PIPE

Table 45

$D = 0.321''$

v ft./sec	h' ft./100ft.	c.	m.	n.
1.335	3.95	82	2.60	1.746
2.333	11.54	84	2.60	1.746
3.301	21.19	87	2.60	1.746
4.278	33.20	91	2.60	1.746
5.311	48.38	93	2.60	1.746
6.796	78.43	94	2.60	1.746
7.182	92.60	91	2.60	1.746

Table 46

$D = 0.282''$

v ft./sec.	h' ft./100ft.	c.	m.	n.
1.375	4.19	88	3.03	1.746
2.127	11.55	82	3.03	1.746
3.626	29.37	87	3.03	1.746
4.567	43.99	90	3.03	1.746
5.271	56.29	92	3.03	1.746
5.953	69.44	93	3.03	1.746
6.513	92.30	88	3.03	1.746

SAPH & SCHODER
BRASS PIPE

Table 47

D=0.261"

V ft./sec.	h' ft./100 ft.	C	m	n.
1.809	9.53	81	3.39	1.744
2.865	21.32	84	3.39	1.744
4.002	39.17	87	3.39	1.744
4.940	55.18	91	3.39	1.744
5.362	59.34	95	3.39	1.744
5.727	72.32	92	3.39	1.744
7.016	97.40	97	3.39	1.744

Table 48

D = 0.221"

V ft./sec	h' ft./100 ft.	C	m.	n.
1.270	4.47	88	4.25	1.733
2.250	17.21	83	4.25	1.733
3.294	33.48	84	4.25	1.733
4.115	49.61	86	4.25	1.733
5.426	82.00	88	4.25	1.733

SAPH & SCHODER
BRASS PIPE

Table 49

D = 0.179"

V ft./sec.	h' ft./100 ft	c	m	n.
1.743	13.80	78	5.52	1.745
2.608	29.28	79	5.52	1.745
3.122	55.05	82	5.52	1.745
3.780	62.20	79	5.52	1.745
4.859	97.90	80	5.52	1.745

Table 50

D = 0.151"

V ft./sec.	h' ft./100 ft.	c.	m.	n.
1.767	11.53	93	6.36	1.774
2.537	33.84	78	6.36	1.774
3.276	52.66	81	6.36	1.774
3.730	72.47	78	6.36	1.774

Table 51

D = 0.107"

V ft./sec.	h' ft./100 ft.	c	m	n
1.378	18.29	69	9.78	1.771
1.614	19.89	77	9.78	1.771
2.282	32.24	85	9.78	1.771
2.620	47.25	85	9.78	1.771
2.866	58.49	79	9.78	1.771
3.230	76.60	78	9.78	1.771
4.000	100.00	85	9.78	1.771.

SAPH and SCHODER

GALVANIZED PIPE

Table 52

D = 1.036"

V ft./sec.	h' ft./100ft	c	m	n.
2.795	5.88	76	0.820	1.931
3.111	7.37	78	0.820	1.931
4.216	13.21	79	0.820	1.931
6.041	26.82	79	0.820	1.931
7.452	39.59	80	0.820	1.931
8.762	54.00	81	0.820	1.931
10.036	70.89	81	0.820	1.931

Table 53

D = 0.805"

V ft./sec.	h' ft./100ft.	c	m	n.
2.618	4.99	90	0.905	1.802
3.913	10.40	94	0.905	1.802
5.708	20.60	97	0.905	1.802
7.060	30.06	99	0.905	1.802
8.321	41.11	100	0.905	1.802
9.469	51.61	101	0.905	1.802
10.554	64.87	101	0.905	1.802
11.470	75.83	102	0.905	1.802

SAPH & SCHODER
GALVANIZED PIPE

Table 54

$D = 0.627''$

V ft./sec.	h' ft./100ft	C	m	n
2.460	7.36	79	1.320	1.863
3.894	16.72	83	1.320	1.863
5.747	33.62	87	1.320	1.863
7.909	61.20	90	1.320	1.863
10.223	96.62	92	1.320	1.863

Table 55

$D = 0.498''$

V ft./sec	h' ft./100ft	C	m	n
1.6.69	5.03	74	1.74	1.906
2.487	10.34	76	1.74	1.906
3.634	21.12	80	1.74	1.906
5.499	46.20	80	1.74	1.906
7.240	79.15	81	1.74	1.906
7.877	91.35	81	1.74	1.906

Table 56

$D = 0.354''$

V ft./sec.	h' ft./100ft	C	m	n
1.305	5.97	62	3.52	1.961
1.856	11.94	63	3.52	1.961
2.744	25.69	63	3.52	1.961
3.756	47.50	64	3.52	1.961
5.025	84.05	64	3.52	1.961

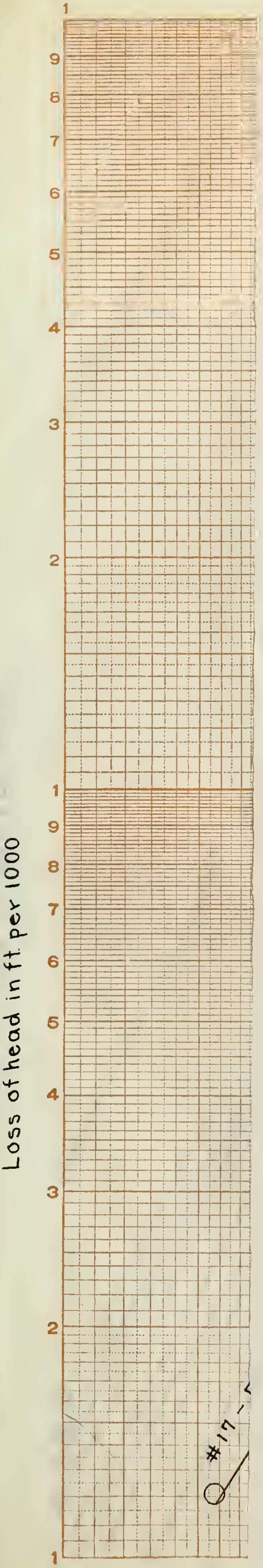
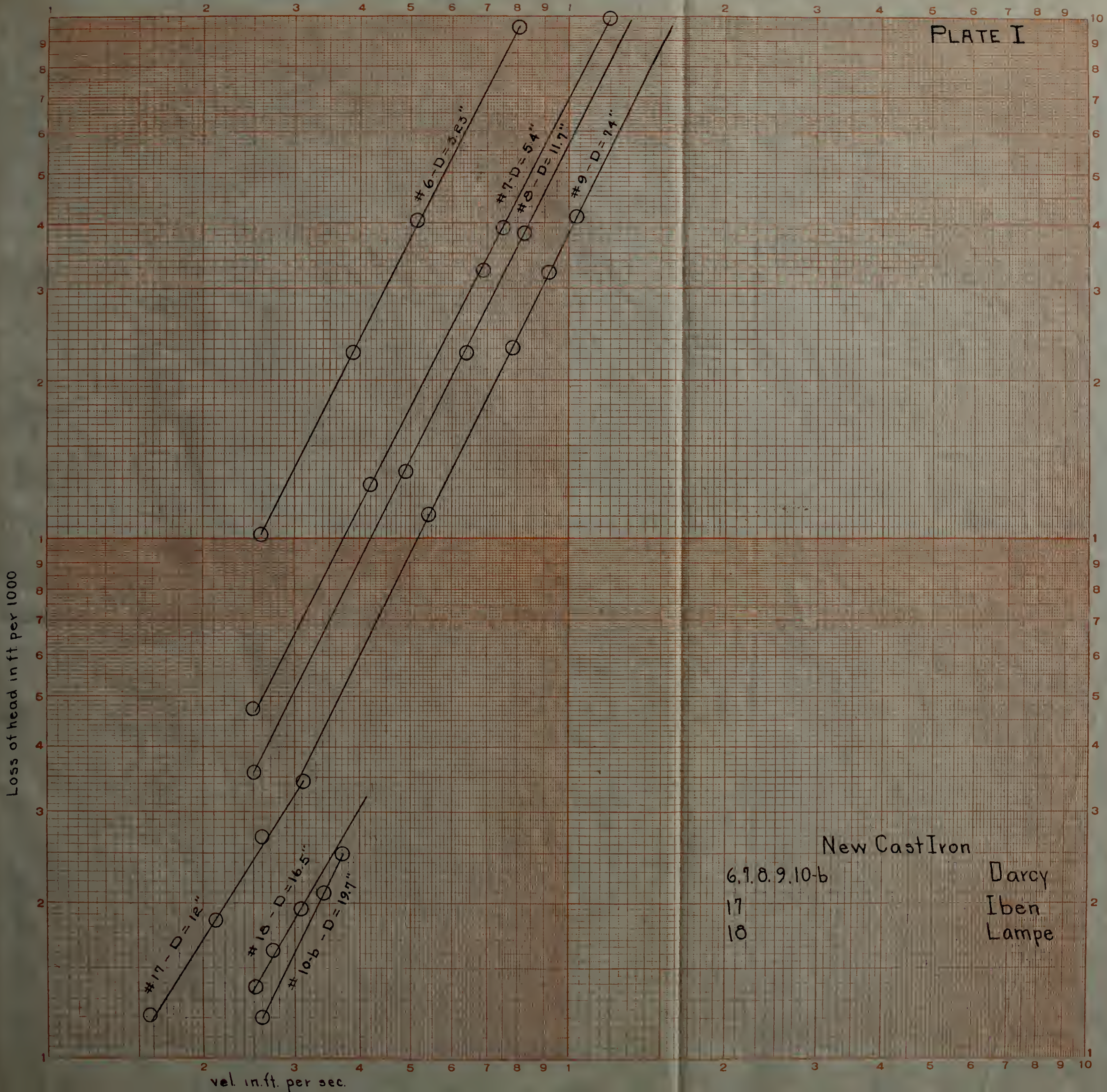
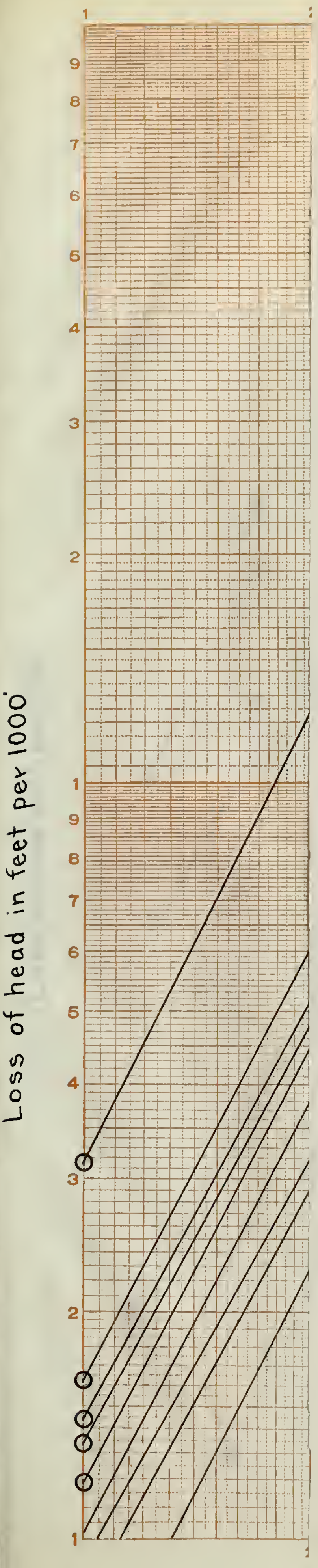

Loss of head in ft. per 1000
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
#17 -

PLATE I

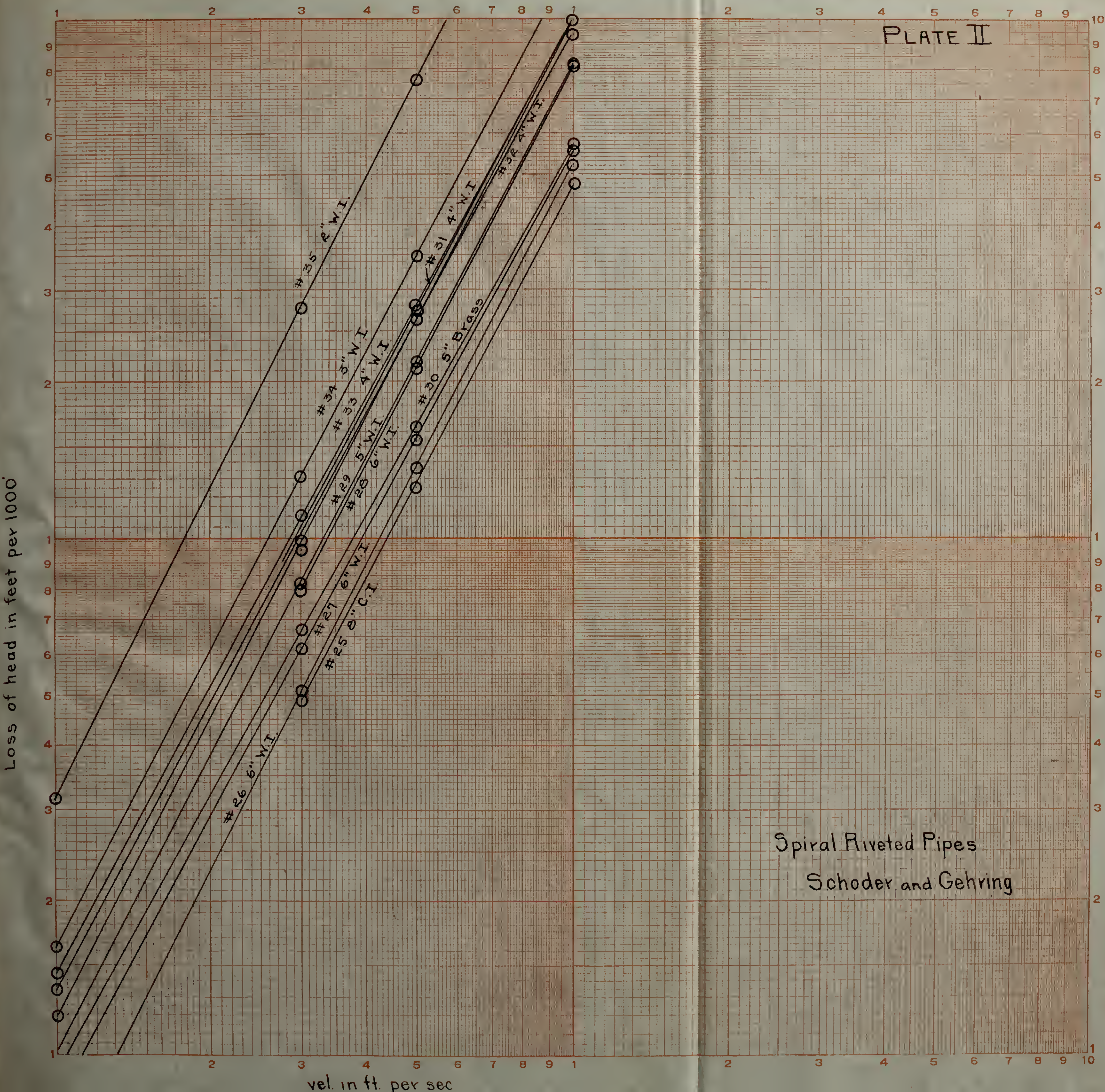


COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.



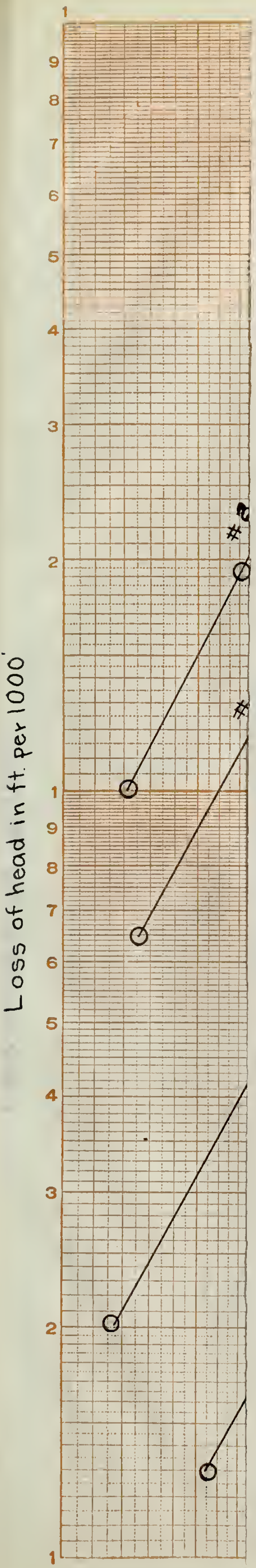
Loss of head in feet per 1000'
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1

PLATE II



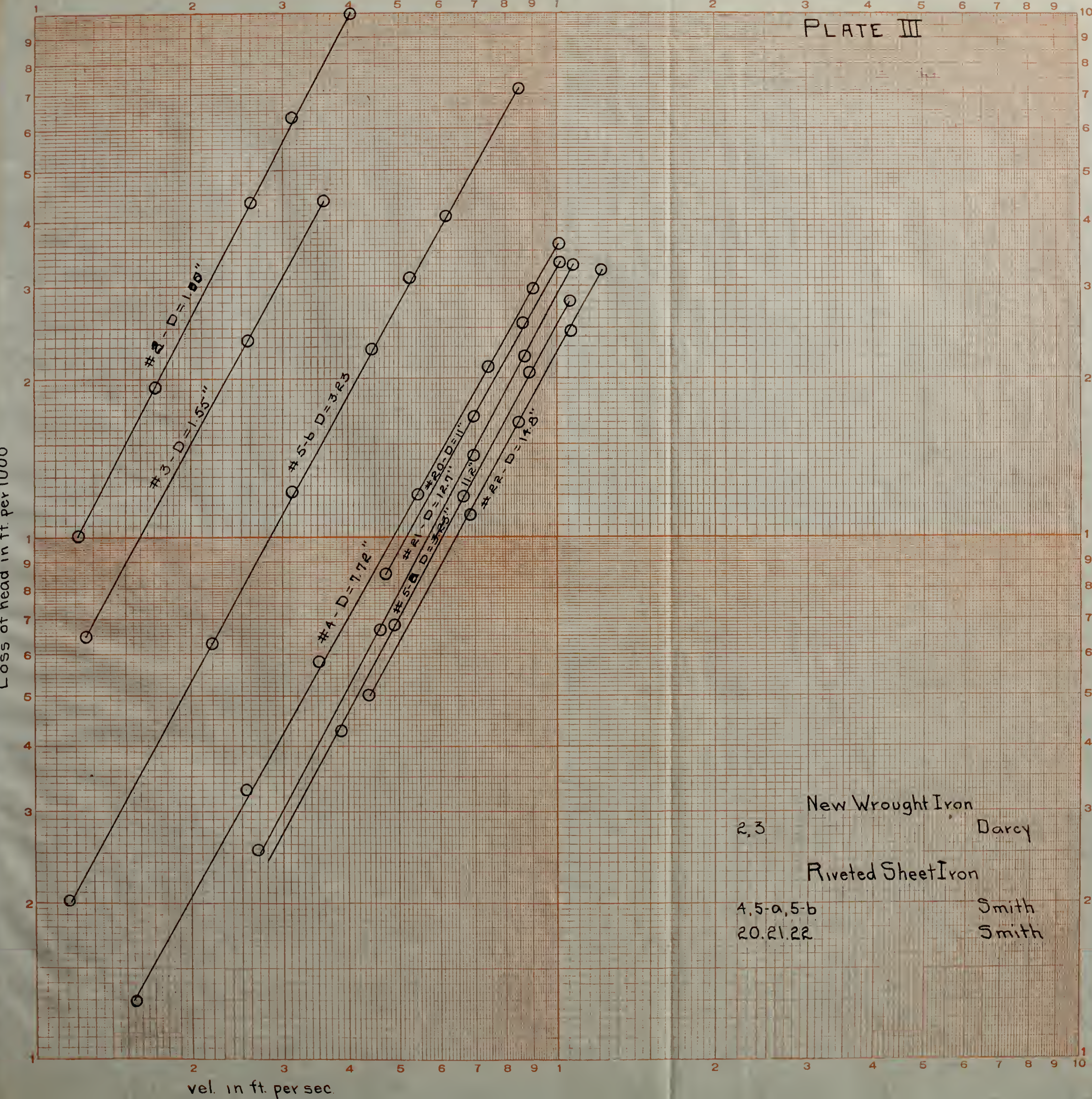
Spiral Riveted Pipes
Schoder and Gehring

COPYRIGHT 1908. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.



Loss of head in ft. per 1000'
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
#2
#1

PLATE III



COPYRIGHT 190 J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

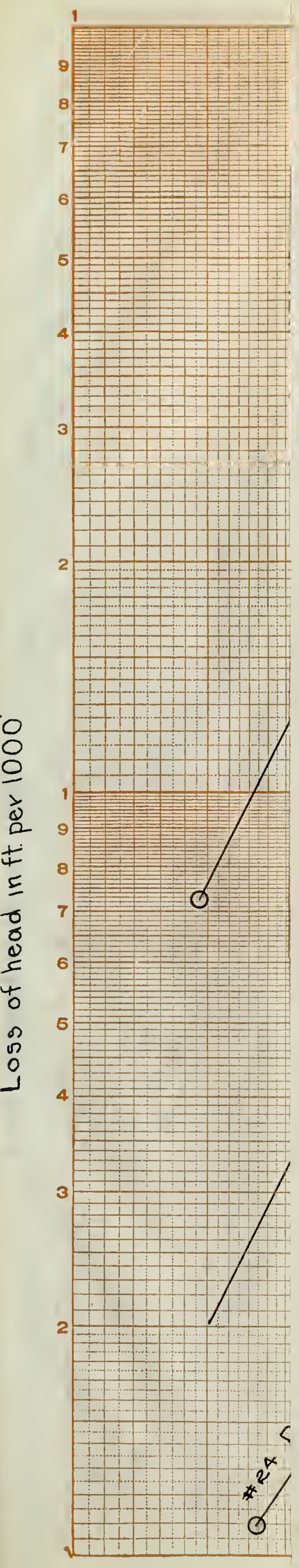
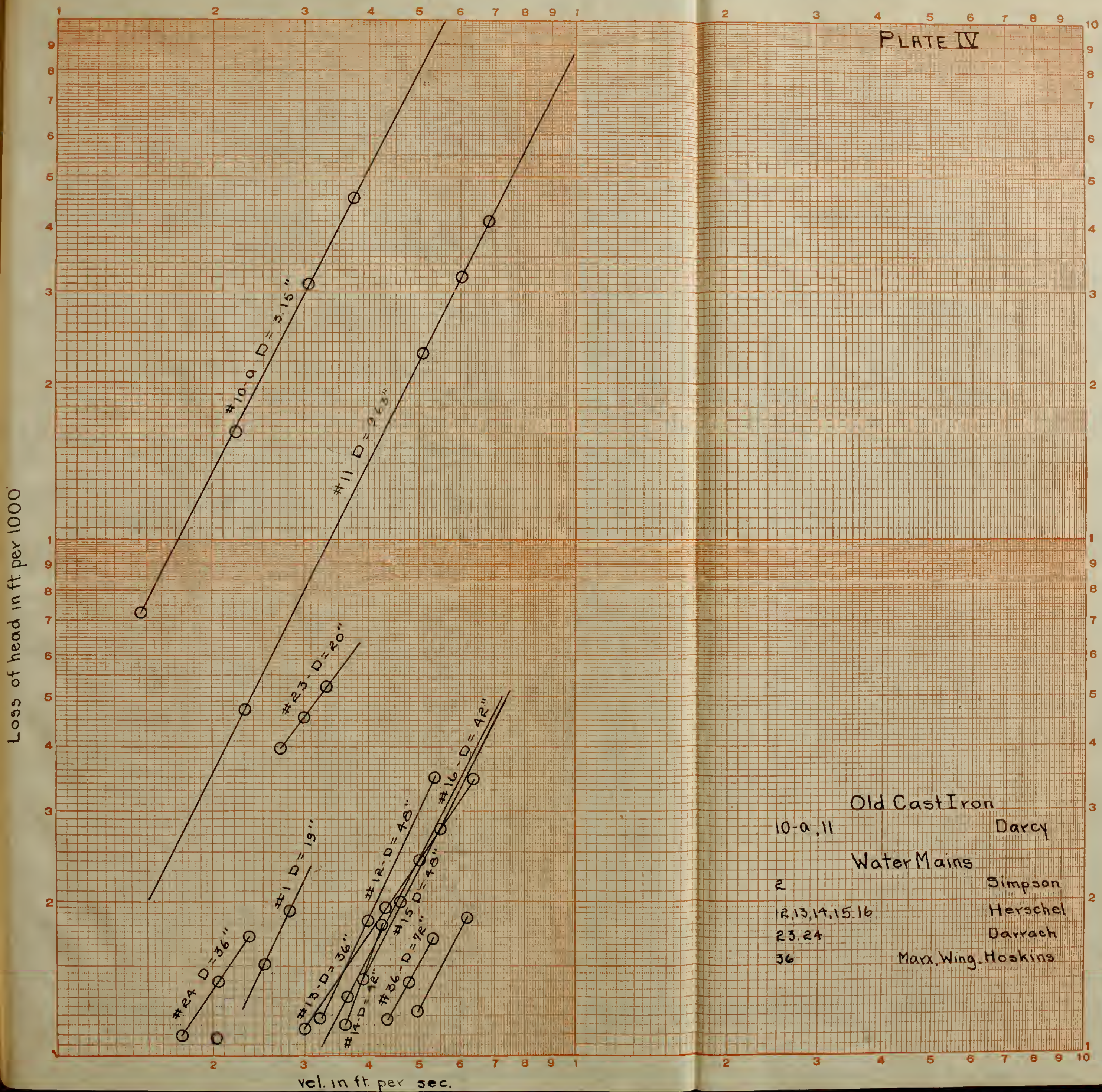

Loss of head in ft. per 1000'
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
#24

PLATE IV



COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

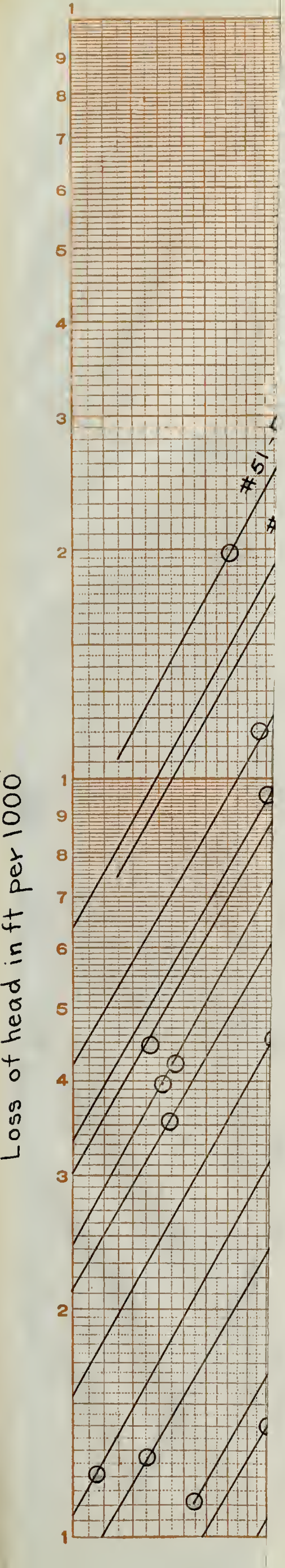
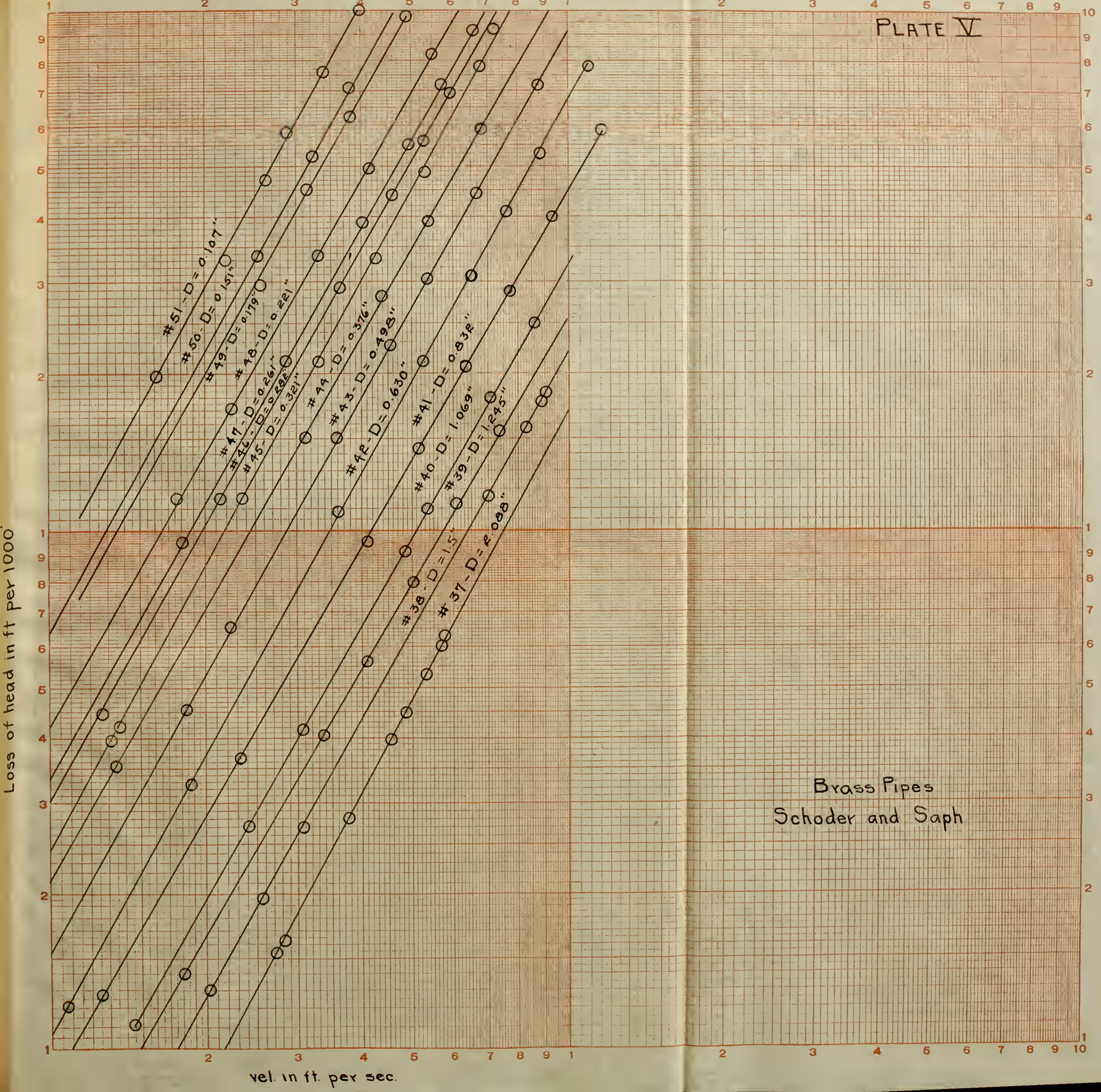

Loss of head in ft per 1000'
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
#51
#

PLATE V



Brass Pipes
Schoder and Saph

COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

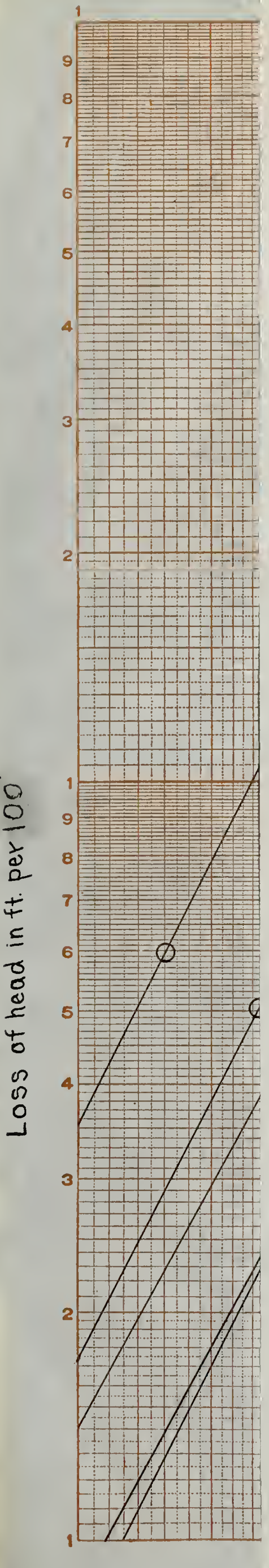
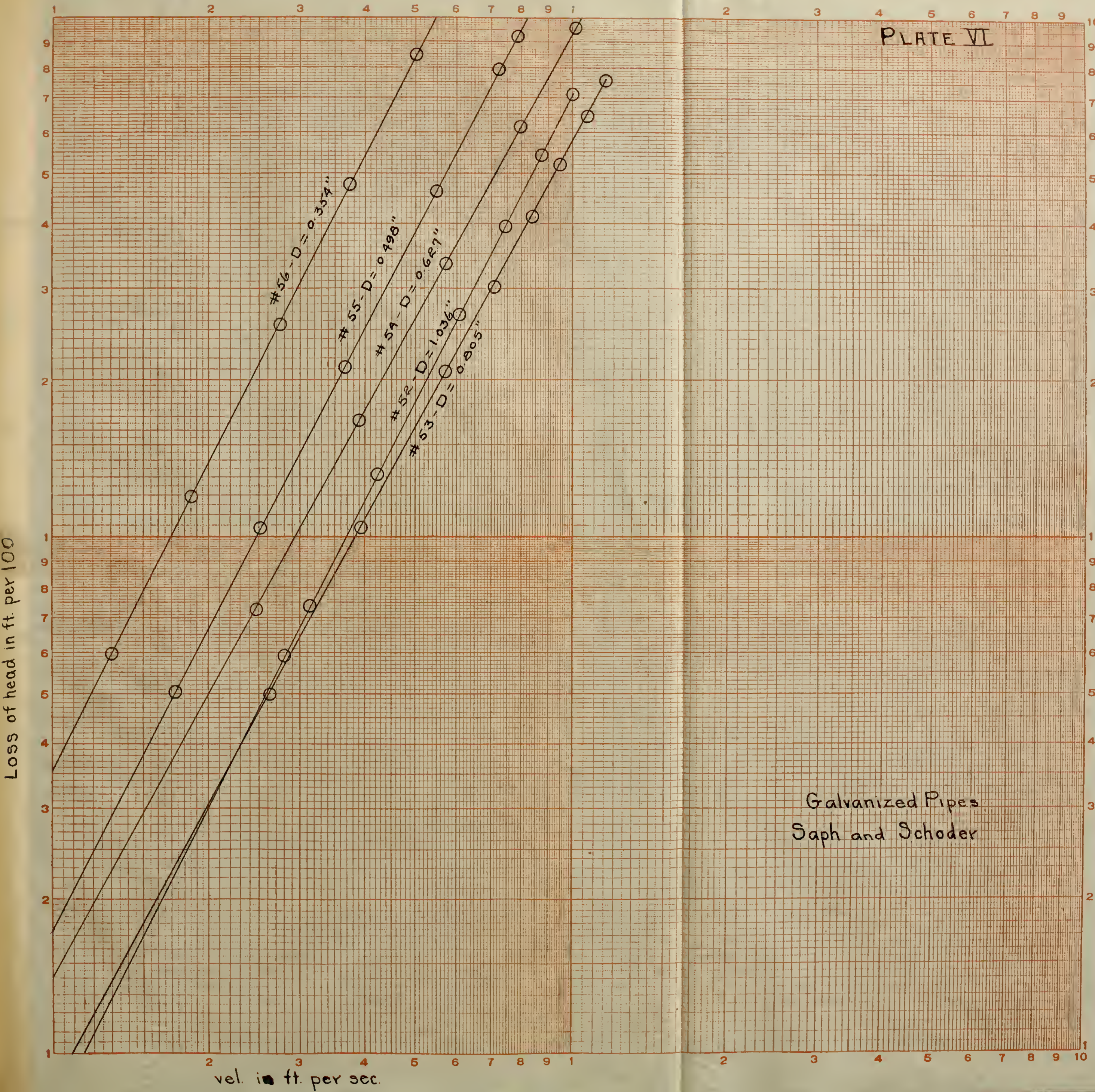

Loss of head in ft. per 100'
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1

PLATE VI



Galvanized Pipes
Saph and Schoder

COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

PLATE VII

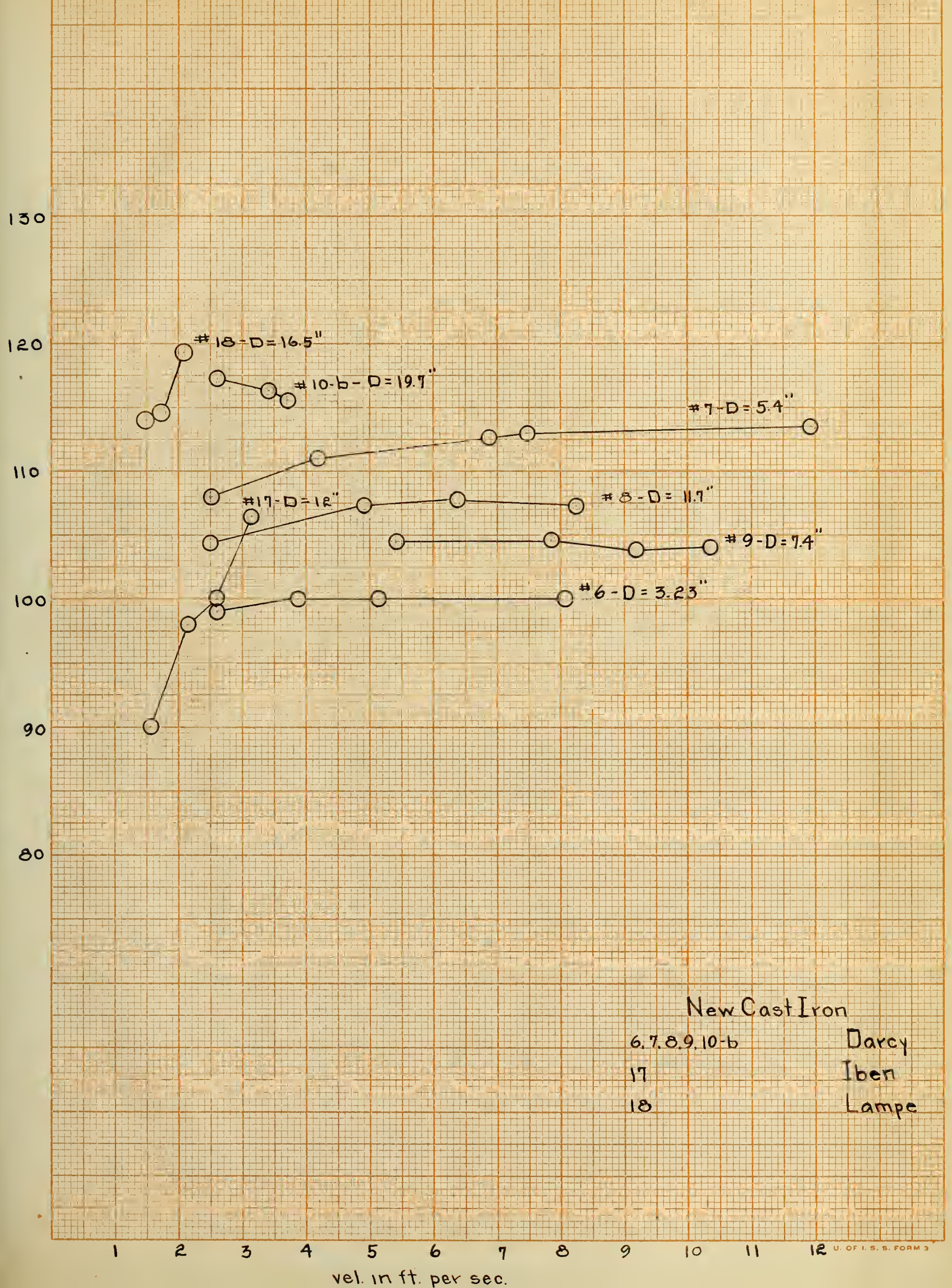
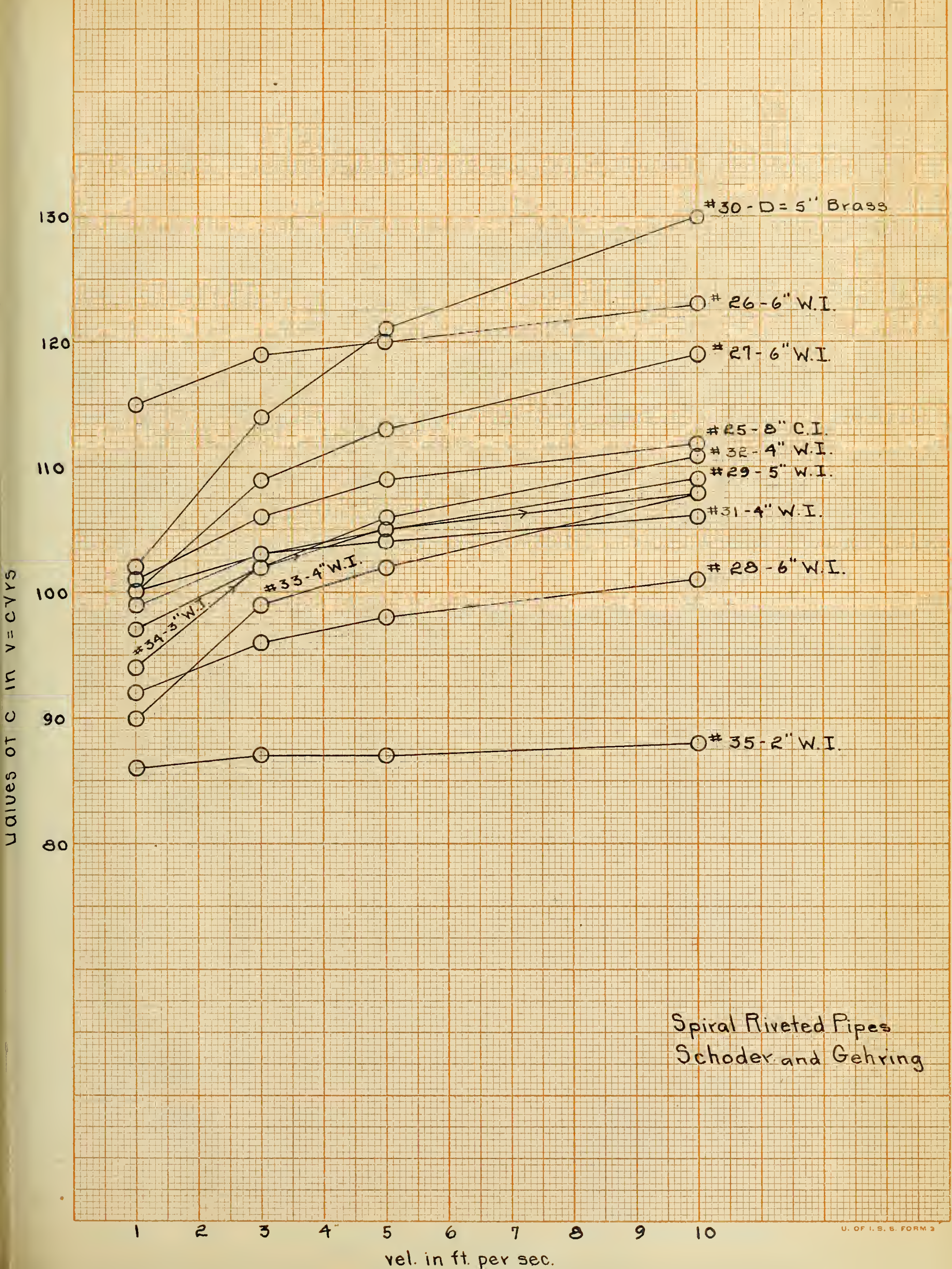

130
120
110
100
90
80
1
2
3
4
5
6
7
8
9
10
11
12
vel. in ft. per sec.
#18 - D = 16.5"
#10-b - D = 19.7"
#7 - D = 5.4"
#17 - D = 12"
#8 - D = 11.7"
#9 - D = 7.4"
#6 - D = 3.23"
New Cast Iron
6.7.8.9.10-b Darcy
17 Iben
18 Lampe
U. OF I. S. S. FORM 3

PLATE VIII



Spiral Riveted Pipes
Schoder and Gehring

U. OF I. S. B. FORM 3

PLATE IX

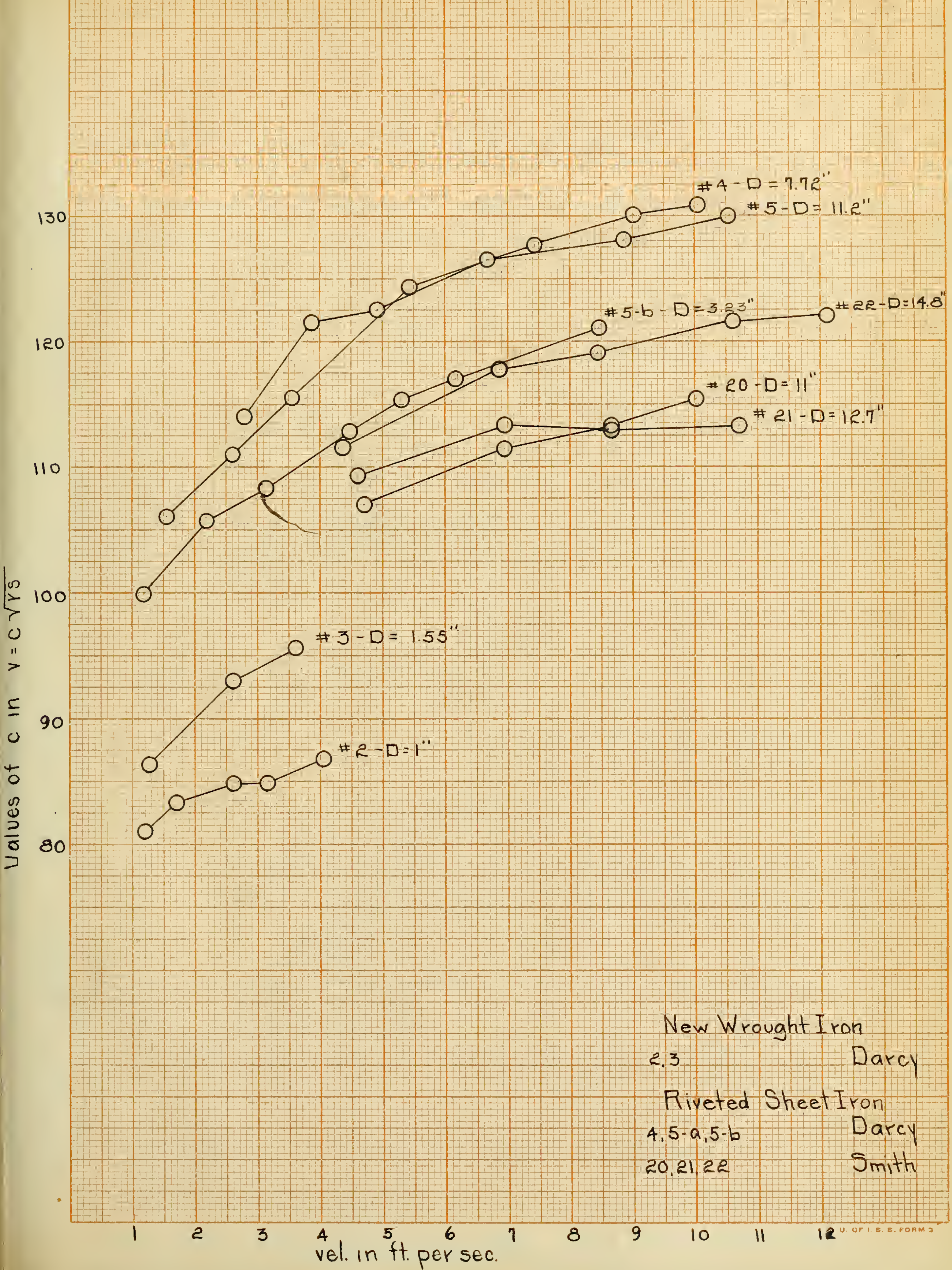

#4 - D = 7.72"
#5 - D = 11.2"
#5-b - D = 3.23"
#22 - D = 14.8"
#20 - D = 11"
#21 - D = 12.7"
#3 - D = 1.55"
#2 - D = 1"
130
120
110
100
90
80
Values of c in v = c√rs
1
2
3
4
5
6
7
8
9
10
11
12
vel. in ft. per sec.
New Wrought Iron
2, 3
Darcy
Riveted Sheet Iron
4, 5-a, 5-b
Darcy
20, 21, 22
Smith
U. OF I. S. S. FORM 3

PLATE X

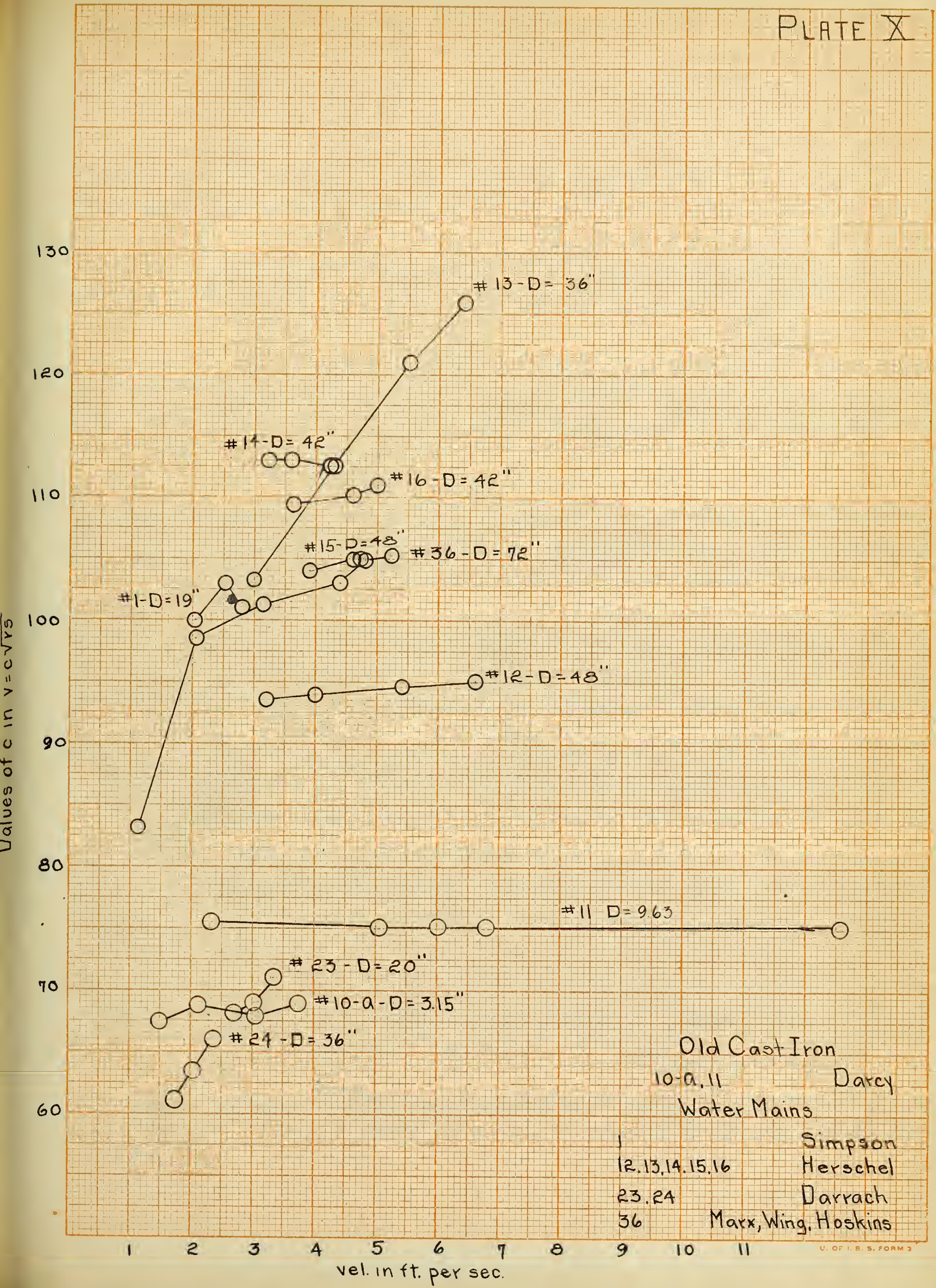
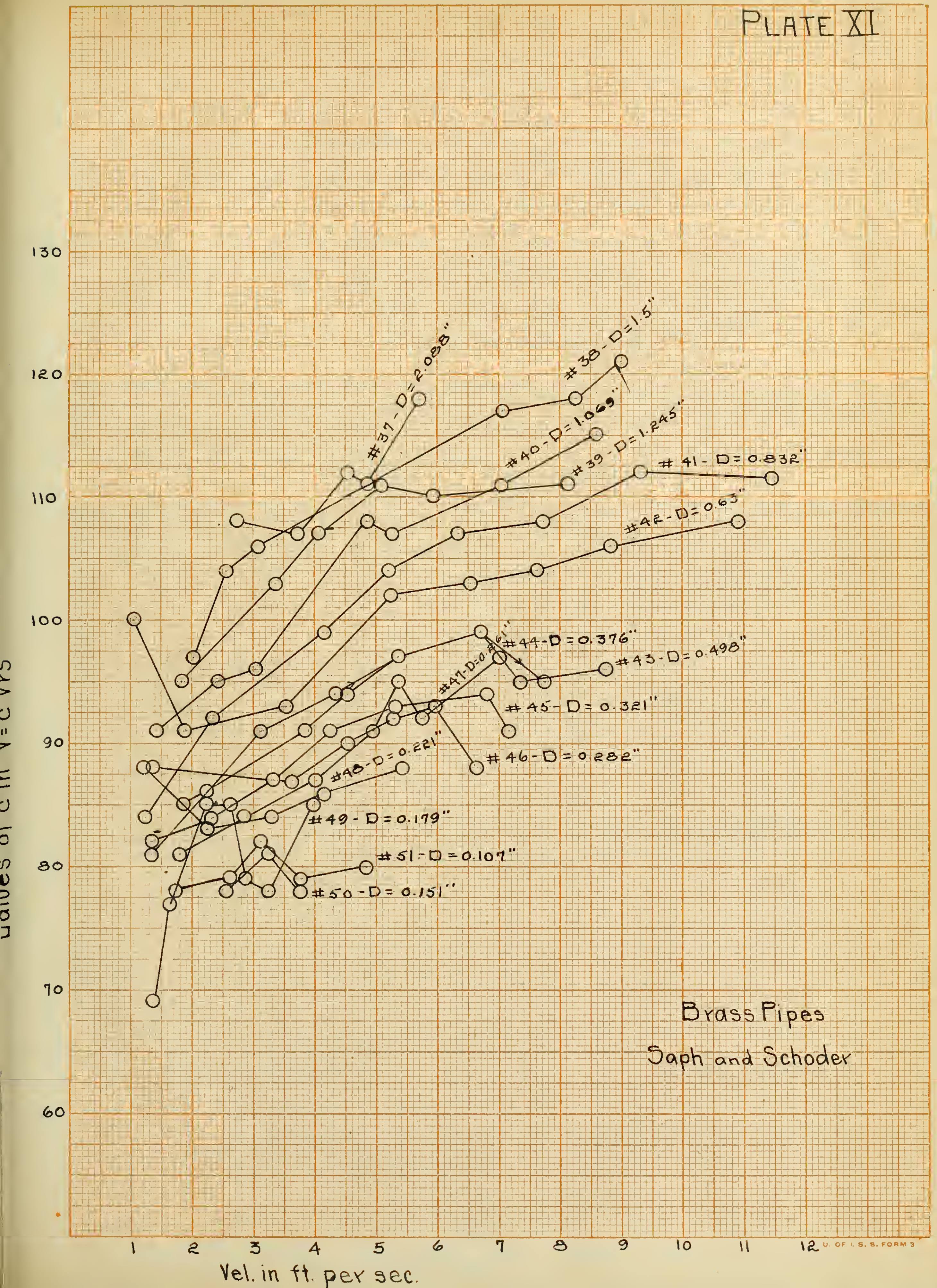
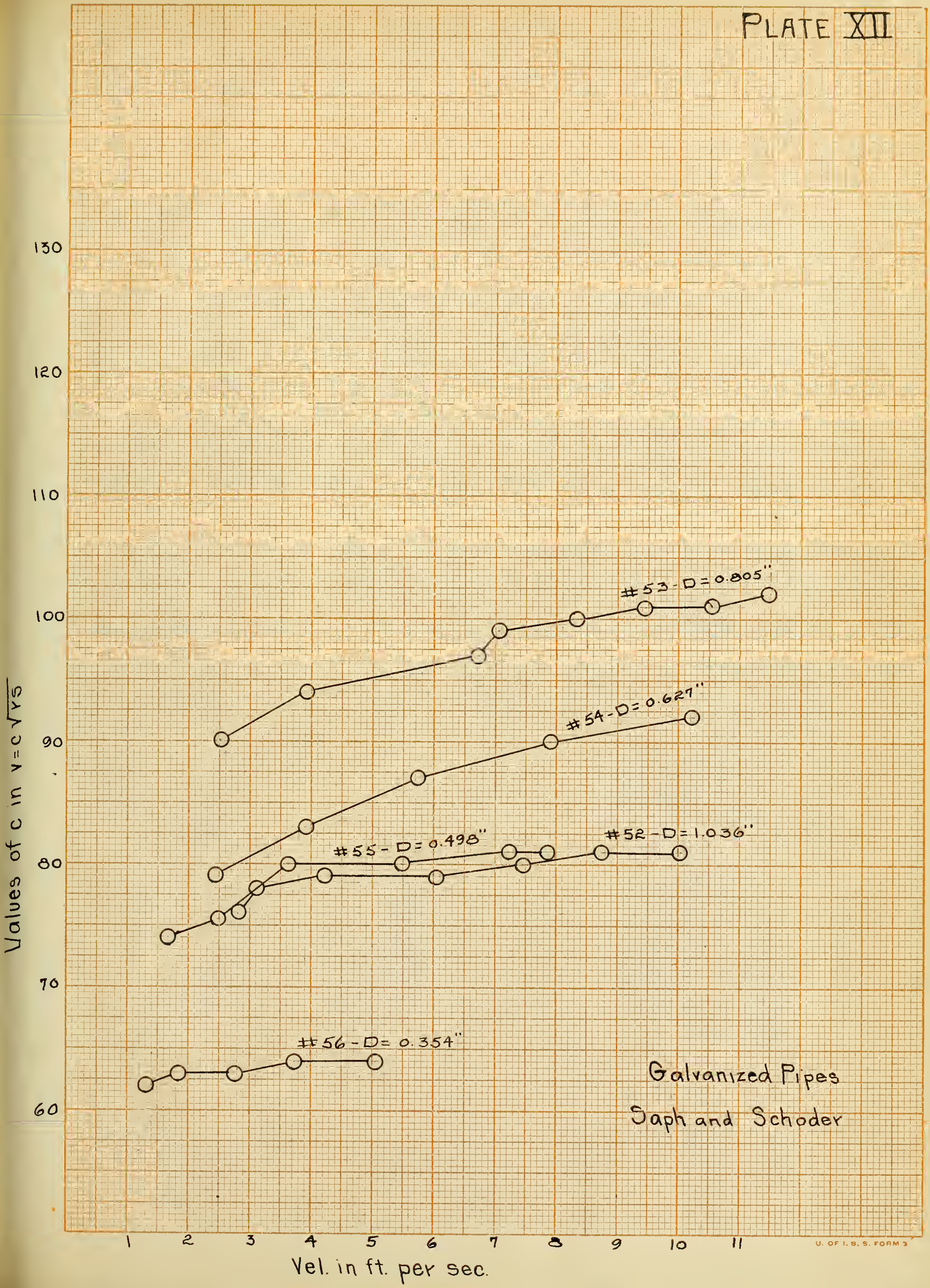

Values of c in v=c√rs
130
120
110
100
90
80
70
60
vel. in ft. per sec.
1
2
3
4
5
6
7
8
9
10
11
#13-D= 36"
#14-D= 42"
#16-D= 42"
#15-D=48"
#36-D= 72"
#1-D=19"
#12-D=48"
#11 D= 9.63
#23-D= 20"
#10-a-D= 3.15"
#24-D= 36"
Old Cast Iron
10-a, 11 Darcy
Water Mains
1 Simpson
12, 13, 14, 15, 16 Herschel
23, 24 Darrach
36 Marx, Wing, Hoskins
U. OF I. S. S. FORM 3

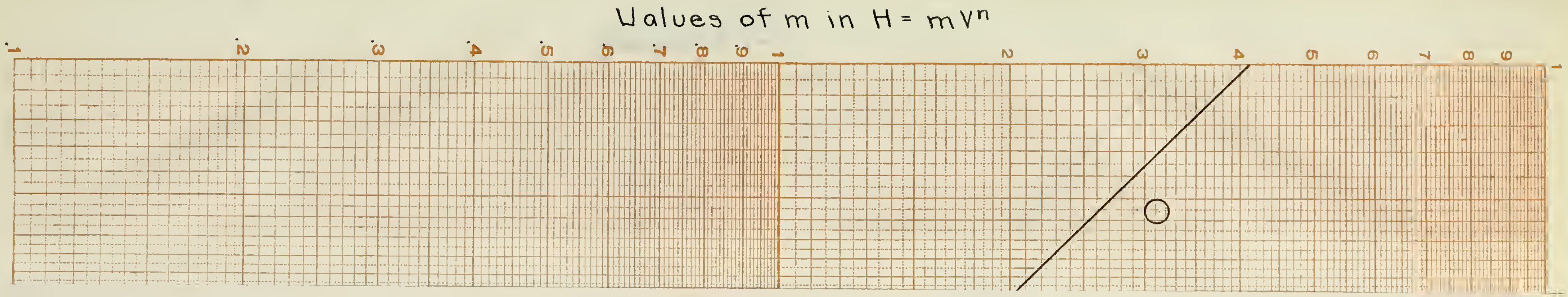
PLATE XI

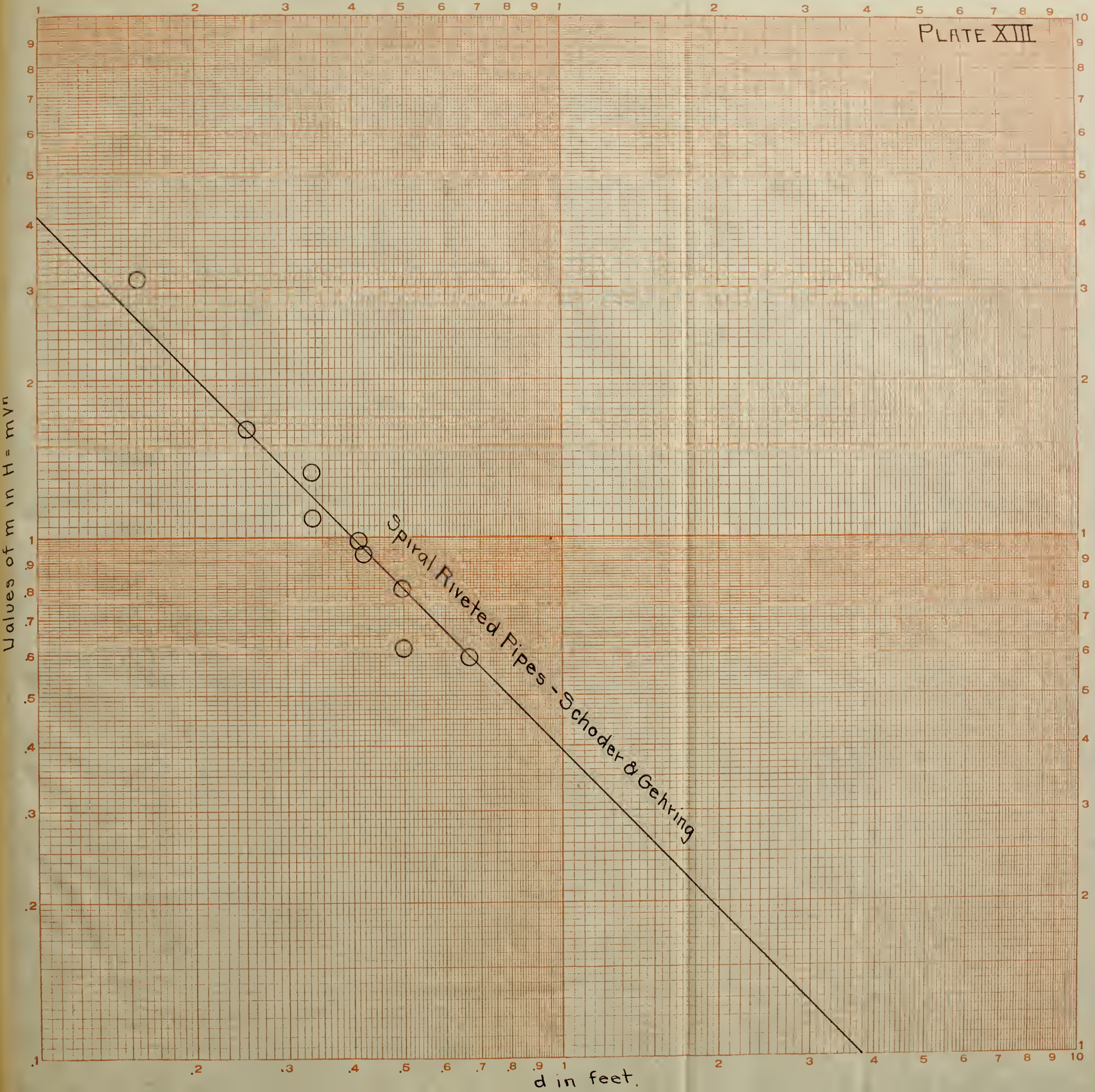


Brass Pipes
Saph and Schoder

PLATE XII


Values of c in v=c√rs
130
120
110
100
90
80
70
60
1
2
3
4
5
6
7
8
9
10
11
Vel. in ft. per sec.
#53 - D = 0.805"
#54 - D = 0.627"
#55 - D = 0.498"
#52 - D = 1.036"
#56 - D = 0.354"
Galvanized Pipes
Saph and Schoder
U. OF I. S. S. FORM 3


Values of m in H = mV^n
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
1



COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

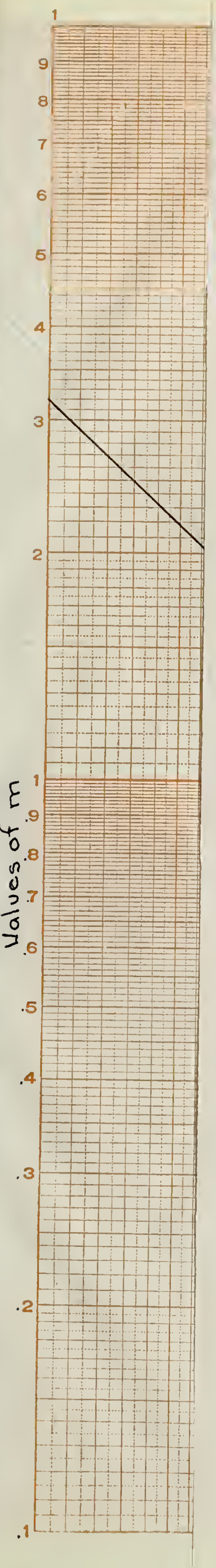
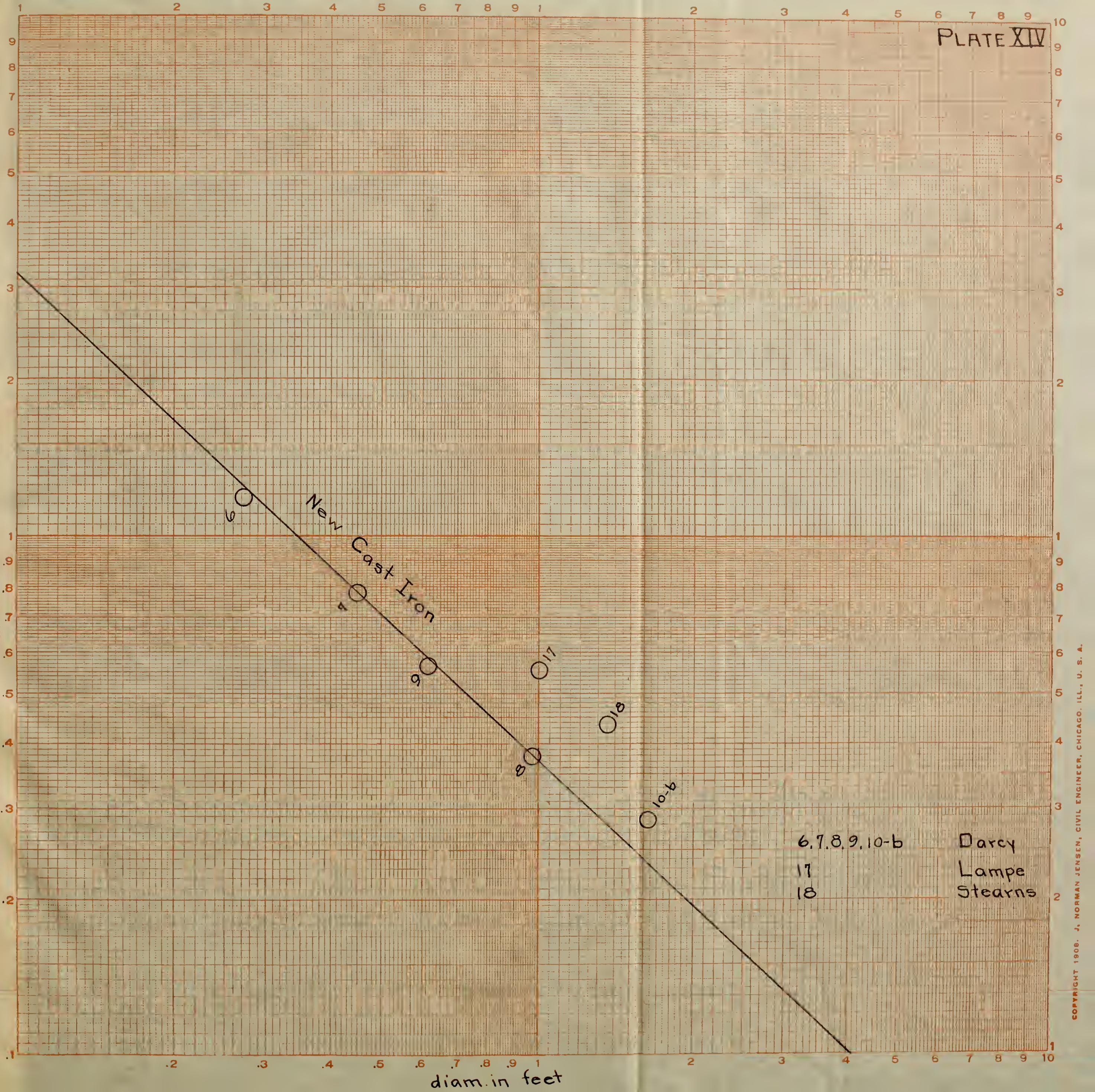

1
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
Values of m

PLATE XIV



COPYRIGHT 1906. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

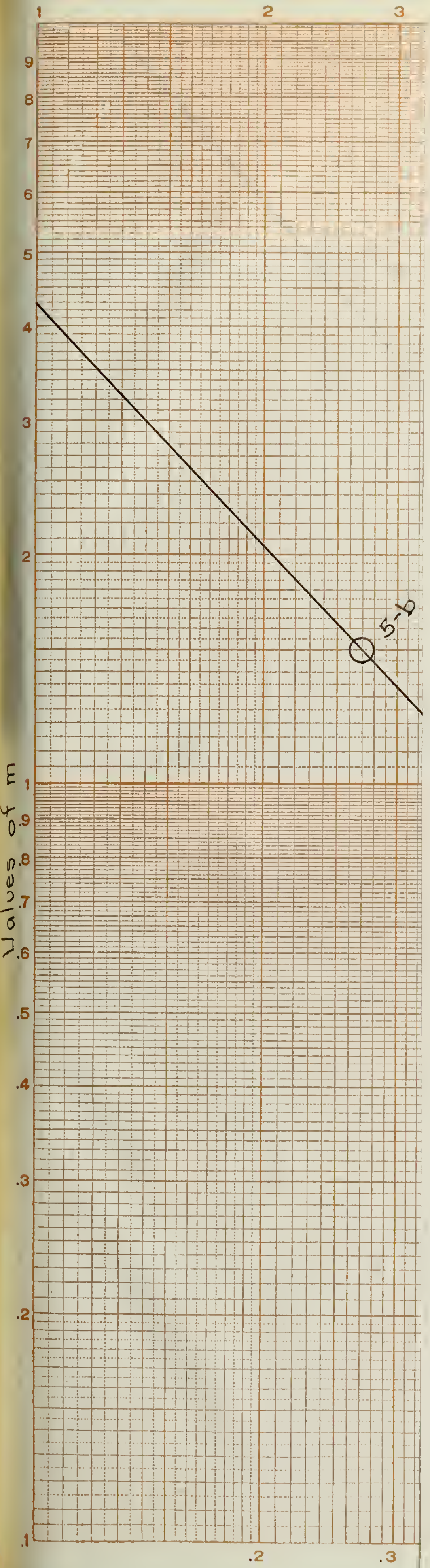
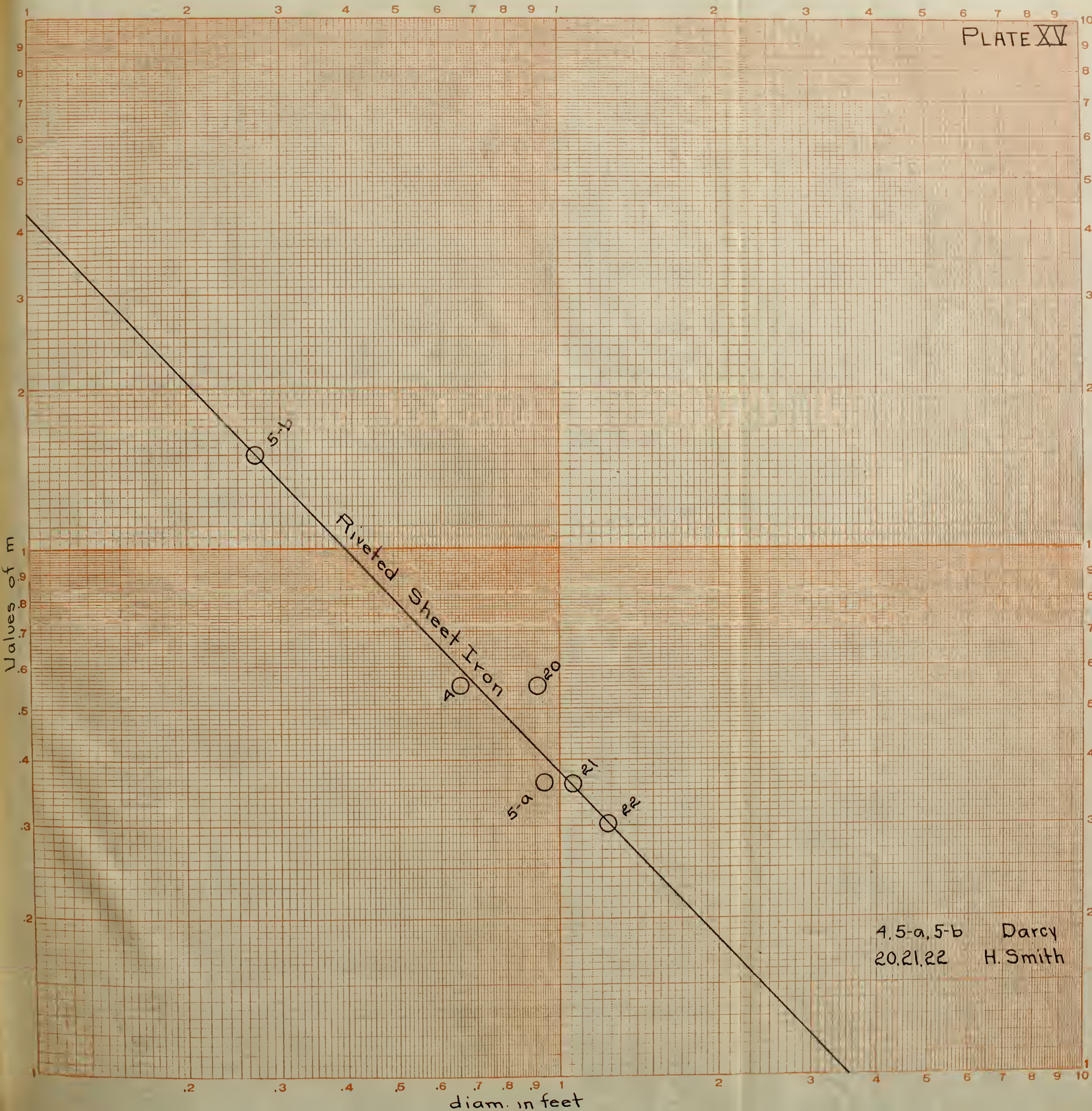
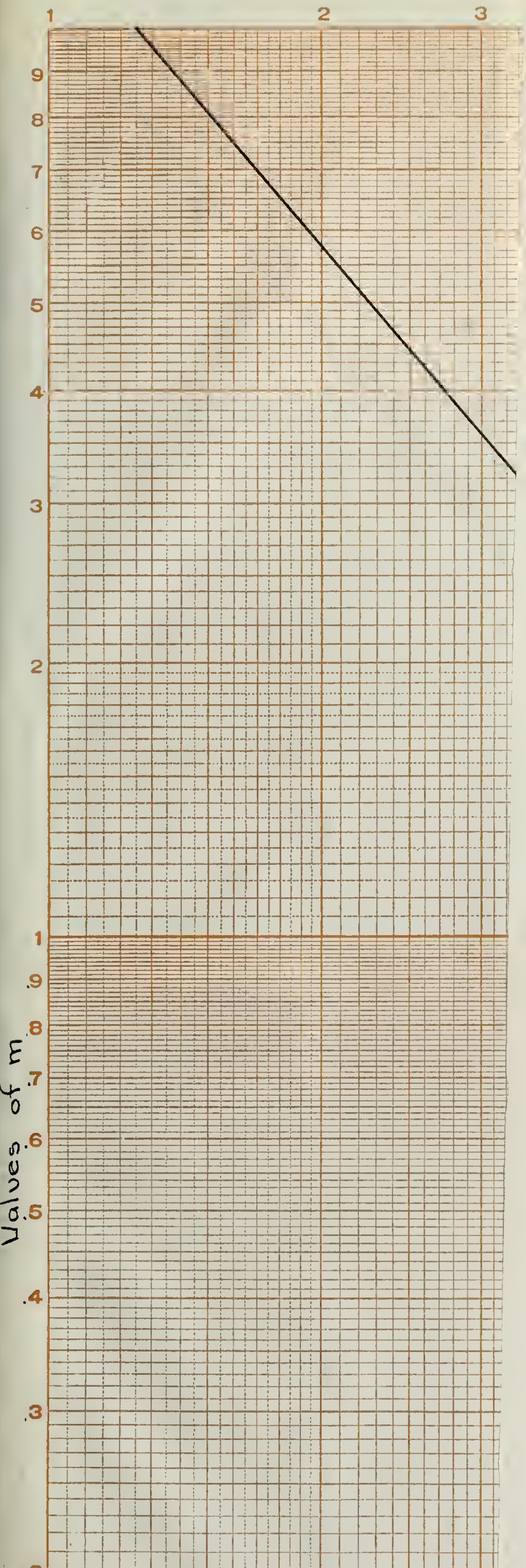

1
2
3
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
.2
.3
Values of m
5-b

PLATE XV

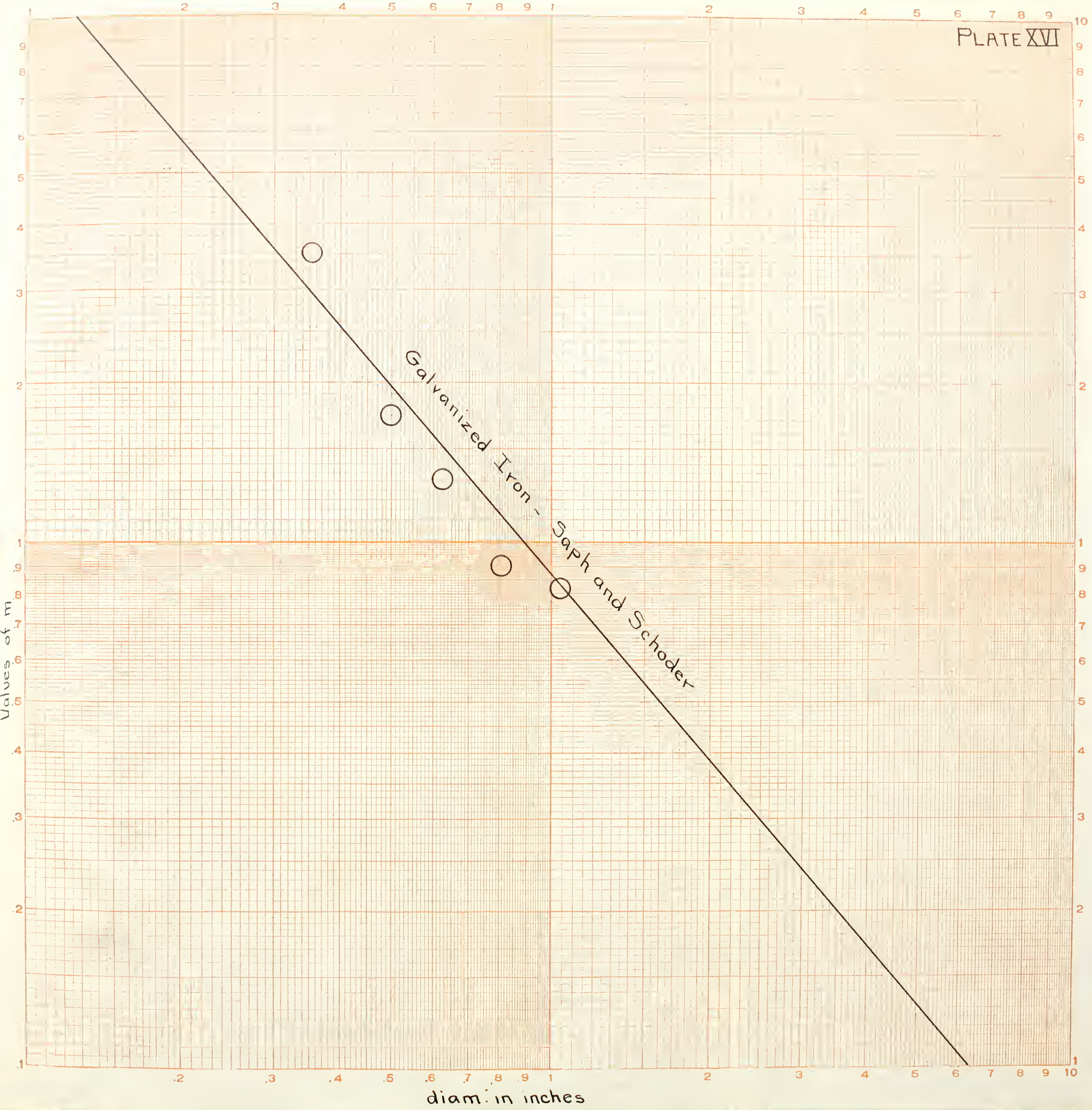


COPYRIGHT 19[illegible]. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.



1
2
3
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
.2
.3
Values of m

PLATE XVI



COPYRIGHT 1908. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

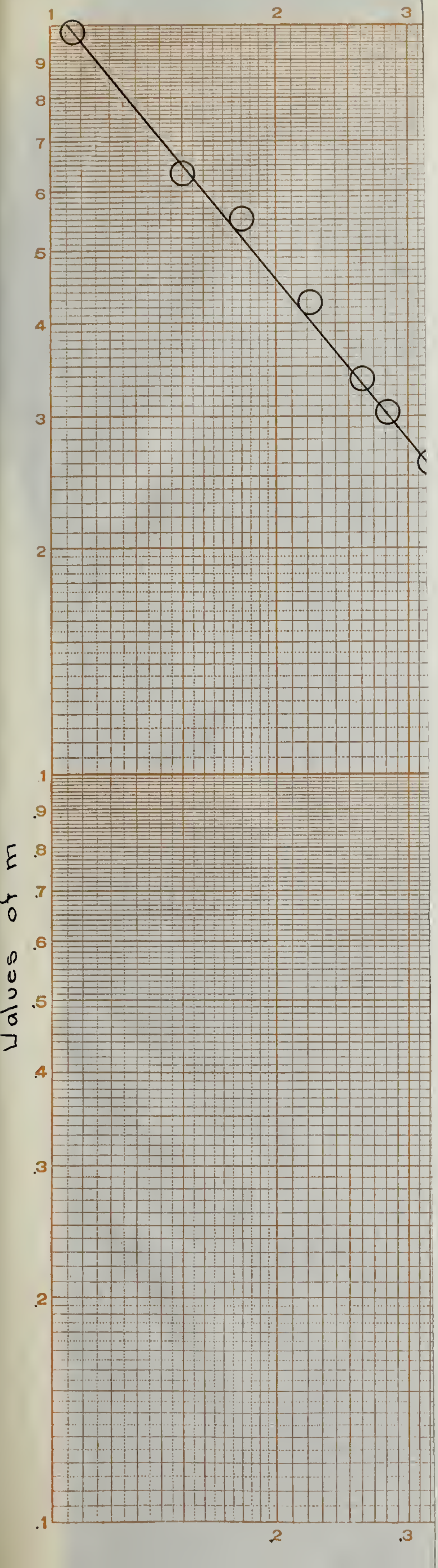
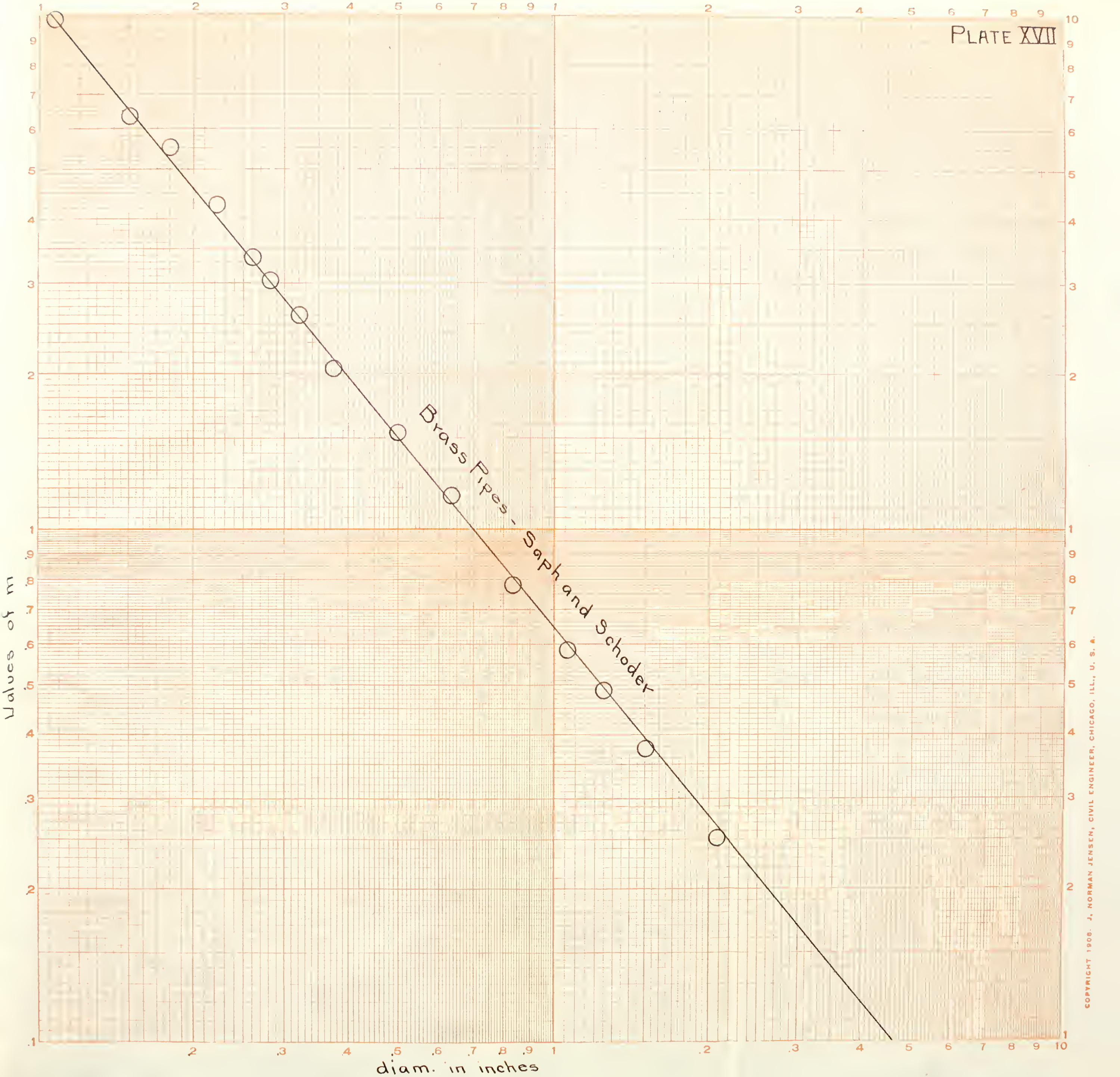

1
2
3
9
8
7
6
5
4
3
2
.1
.9
.8
.7
.6
.5
.4
.3
.2
.1
.2
.3
Values of m

PLATE XVII



COPYRIGHT 1908. J. NORMAN JENSEN, CIVIL ENGINEER, CHICAGO, ILL., U. S. A.

COMMENTS.

(1). At present there exists no empirical formula which accurately represents the law of water flowing in pipes.

(2). The value of the coefficient c in the Chezy formula $v = c(rs)^{1/2}$ depends on the condition of the interior surface of the pipes. c increases with increasing values of v. In the majority of cases, c increases as the diameter of the pipes increase. For practical purposes, this variation of c could be estimated for different sized pipes and different velocities with fair accuracy from the tables in this thesis. Kutter's formula, which was devised to compute the value of c in the Chezy formula, is cumbersome, and gives results far from the truth in many cases. It has, however, a wide use.

Tables have been prepared to admit of the easy solution of this formula for various conditions and sizes of pipes.

(3). Probably the best formula in practical use is the Hazen-Williams formula, $v = cr^{0.63}s^{0.54}0.001^{-0.04}$. The authors have devised an ingenious hydraulic slide-rule based on their formula. The exponents used are selected as representing as nearly as possible, average conditions.

(4). The effect of temperature on the loss of head in pipes is greater in small pipes than in larger and is also greater below the critical velocity than above it. The principal effect of temperature is in changing the viscosity of the water adhering to the wetted surface. It is almost a negligible quantity in pipes above 2 inches in diameter.

(5). The equation $H = mv^n$ represents very accurately the conditions of flow in any particular pipe, m and n being constant

for that pipe for all velocities. The following values of n are suggested.

Commercial Pipes.

New Cast Iron,	1.80--1.85
New Wrought Iron,	1.85--1.90
Riveted Sheet Iron,	1.95--2.00
Brass Pipes - Smooth interior surface,	1.75
Galvanized Iron,	1.87--1.92
Water Main - In use,	1.80--1.90

(c). The plotting of the value of m against the diameter in Saph and Schoder's experiments on brass pipes shows them to be very consistent. Their experiments on galvanized pipes are very inconsistent. This is to be expected because of the great effect small variations of diameter will have in such small pipes.

Schoder and Gehring's experiments on spiral-riveted pipes are very good. The Riveted Sheet Iron and the New Cast Iron experiments plot up fairly well considering that each group represents several different experimentors. The New Wrought Iron experiments were not plotted because of lack of number. The Water Mains experiments were plotted but no attempt was made to derive an equation because of the wide variance.

Following are the equations, as derived from the curves, which represent the law of the loss of head in friction.

Spiral Riveted,	$H' = 0.391(v^{1.90}/d^{1.03})$
Riveted Sheet Iron,	$H' = 0.376(v^{1.96}/d^{1.05})$
New Cast Iron,	$H' = 0.371(v^{1.85}/d^{0.94})$
Brass,	$H' = 0.306(v^{1.75}/d^{1.225})$

Galvanized Iron, $H' = 0.406(v^{1.90}/d^{1.25})$

In these equations H' is the loss of head in feet of water per 1000 feet of pipe, v is the velocity in feet per second, and d is the diameter of the pipe in feet.

(7). It is impossible to evolve a general formula from existing experiments. There are not enough available experiments at present, on pipes of commercial size, to arrive at any definite conclusions.

BIBLIOGRAPHY.

Hamilton Smith's Hydraulics.

Gibson's Hydraulics.

Lea's Hydraulics.

Herschell's 115 Experiments.

Transactions of American Society of Civil Engineers, Volumes 2, 7, 12, 14, 22, 35, 36, 44.

Engineering News, April 2, 1892. pp. 329-30.
" " Nov. 10, 1898.
" " Dec. 19, 1901.
" " Volume 45, p. 262.

Engineering Record, Aug. 29, 1908.
" " Mar. 10, 1900.
" " Feb. 15, 1896.

Surveyor, July 16, 1909.

Journal Association Engineering Societies, Jan. 1894.
" " " " June, 1897.

Journal New England W. W. Association, June, 1892.

The Compass, Jan. 1893.

Turneaure and Russell - "Water Supply",

Hazen and Williams - Tables.

UNIVERSITY OF ILLINOIS-URBANA

3 0112 082196657